Demetrios Demetriades
Kenji Inaba
Philip D. Lumb
Editors

Atlas of Critical Care Procedures

Springer

Atlas of Critical Care Procedures

Demetrios Demetriades • Kenji Inaba
Philip D. Lumb
Editors

Atlas of Critical Care Procedures

Springer

Editors
Demetrios Demetriades
Department of Surgery
University of Southern California
Los Angeles
California
USA

Kenji Inaba
Department of Surgery
University of Southern California
Los Angeles
California
USA

Philip D. Lumb
Department of Anethesiology
University of Southern California
Los Angeles
California
USA

Scientific Illustration: Alexis Demetriades

ISBN 978-3-319-78366-6 ISBN 978-3-319-78367-3 (eBook)
https://doi.org/10.1007/978-3-319-78367-3

Library of Congress Control Number: 2018961744

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To my parents, my wife Elizabeth, my daughters Alexis and Stefanie, and my son Nicholas.

Demetrios Demetriades

To Christine

Philip Lumb

To my parents, Susie and Koji, thank you for all of your support.

Kenji Inaba

Foreword

The ICU in the Baltimore City Hospital was organized in the mid-1950s by a young anesthesiologist named Peter Safar. Peter determined that patients cared for in his ICU would benefit from the continuous presence of a seasoned physician alongside a group of expert critical care nurses and other professionals. His invention of the intensivist-led, multiprofessional team secured Peter's place as one of the founding fathers of critical care medicine. Peter would go on to become the second President of the Society of Critical Care Medicine, Professor of Anesthesiology at the University of Pittsburgh, and eventually a personal mentor and dear friend.

I knew none of that history in the fall of 1980 when I found myself assigned to that very ICU. I was a surgical intern—precisely one season past graduation from medical school—looking after a dozen very ill patients, including a man who had undergone repair of a large abdominal aortic aneurysm. In those days, the procedures were all "open"—endovascular repair had not yet been conceived—and the associated blood loss and fluid shifts were routinely managed based on interpretation of data gleaned from a pulmonary artery catheter. Every hour the nurse would "shoot an output and measure the pressures"; the intern would compute the various indices using a calculator bolted to a rolling cart; and decisions would be made about the next hour's fluid management.

Around 2:30 in the morning I was summoned to the bedside. The patient had apparently woken with a start and, in his postoperative delirium, had thrashed violently. While the endotracheal tube remained secure, the pulmonary artery catheter had found its way to the floor. According to the nurse, I turned somewhat pale. I called the chief resident who graciously listened to my tale of woe and subsequently uttered three words before severing the connection: "Put it back."

According to the nurse, I was no longer pale. I was chalk white. I explained that I had never "floated a Swan-Ganz" (period jargon—the PA catheter had been invented by Drs. Swan and Ganz). She looked at me, muttered something about "interns," and cheerfully remarked, "No problem, read the package insert, I'll talk you through it."

I learned several things that night. First, critical care nurses are the best professional partners on earth. They just want to get things done right for the patient. Second, package inserts are next to useless—or at least they were at the time. Third, critical care is a discipline with a constellation of procedures that have to be learned, mastered, and passed on. Finally, I learned that a good atlas of critical care procedures didn't exist, and learning was based on the "see one, do one, teach one" model.

Suffice it to say that we completed the 20-min pulmonary artery catheter insertion in just under an hour. The patient survived. I chose critical care as my specialty. I am still teaching—and learning—the finer points of the dozens of procedures performed at the bedside of critically ill patients around the world. And the world now has a first class atlas of critical care.

I could have made good use of Chap. 14 in this new atlas that fall night in Baltimore almost four decades ago. I am sure that I will make good use of all of the other chapters in this new ***Atlas of Critical Care***. I am sure that you will also make good use of the knowledge and insight contained herein.

Timothy G. Buchman, PhD, MD, FACS, FCCP, MCCM

Preface

It is appropriate that the *Atlas of Critical Care's* editorial home is the Los Angeles County + University of Southern California Medical Center (LAC+USC MC), the professional home of Max Harry (Hal) Weil who is credited as being the father of critical care medicine. In 1958 Weil noted that patients were more likely to die at night and postulated that the sickest among them may benefit from personal and specialized care delivered by specially trained professionals; this led to the creation of a four-bed (shock) unit at the LAC+USC MC and is legitimately recognized as the first unit organized for the specific purpose of specialized care. His interests in circulation and cardiovascular pathophysiology led to major developments that are now standard in the field: the "stat lab," lactate measurement, and the concept of continuous cardiovascular and hemodynamic monitoring via computerized systems. Weil spent the majority of his career at the USC and in later years was joined there by another of the three critical care founders, William Shoemaker. The two were members of the Departments of Surgery and Anesthesiology at the USC, and it was our privilege to share their stories and wisdom. Dr. Buchman's foreword recognizes the third partner in critical care's foundation, Dr. Peter Safar; together, these three individuals helped develop the specialty we now recognize, and we hope this *Atlas* reflects well on their creative genius and groundbreaking, transformative innovation.

Critical care medicine has a multidisciplinary past, present, and future; it is multi-professional, team based, and uniquely positioned at the interfaces of anesthesiology, medicine, nursing, pediatrics, pharmacy, respiratory therapy, and surgery, requiring complementary expertise from all participants and consultants in order to effect positive patient outcomes. The practice of critical care relies on invasive techniques from mechanical ventilation to ECMO as well as on invasive monitoring modalities required to ensure appropriate life support functions. In many cases quasi-surgical/invasive techniques are required to establish airway, vascular access and mitigate complications. While expertise abounds in all primary disciplines, the *Atlas of Critical Care* engages procedural experts and utilizes their experience to produce a guide for all practitioners to view the insertion and management of most frequently used life support and monitoring techniques.

Why is such an atlas important today? It is primarily because of the nature of our specialty and the manner in which it is practiced. The techniques may be performed by a single operator, but all require assistance and understanding the physiologic and anatomic placement implications of the device itself: e.g., erosion of an adjacent major vessel, delayed pneumothorax, pulmonary embolism, and impeller rotor failure. Therefore, all members of the team must be familiar with the anatomy of the device as well as the patient, and the *Atlas* provides a procedurally based approach designed for not only the operators and inserters but also the maintainers and assisters who will develop a greater understanding of the device as well as troubleshooting its complications.

The *Atlas of Critical Care* is a multidisciplinary and interdisciplinary resource that motivates and enables more appropriate insertion, management, and troubleshooting of the technically and technologically advanced devices that make the delivery of critical care possible.

Los Angeles, CA — Philip D. Lumb

Acknowledgments

The editors and authors greatly acknowledge the major contributions of Alexis Demetriades, Scientific Illustrator, and Michael Minneti for his help with the Fresh Tissue Dissection Lab.

Contents

Part VII Abdomen

Part I

Airway

1 Endotracheal Intubation: Oral and Nasal

Gillian Morrison and Joshua M. Tobin

1.1 General Principles

- The indications for airway management include protecting the airway from aspiration, providing adequate oxygenation, and providing adequate ventilation (removing carbon dioxide).
- Adequate preoxygenation is the key principle to avoiding desaturation during the apneic period associated with rapid sequence induction. Patients should breathe 10 L of oxygen for 2 min or five vital capacity breaths, prior to induction.
- Simple airway examination can help to determine the likelihood of a difficult airway. A difficult airway is suggested by Mallampati (MP) score III or IV, thyromental (TM) distance <6 cm, limited range of motion of the cervical spine, small chin, overbite, short thick neck, pathology of the airway, and radiation to the neck.

  Mallampati score when looking into an open mouth:
  I = able to visualize all of the soft palate
  II = able to visualize all of the uvula
  III = able to visualize only the base of the uvula
  IV = soft palate not visible
- Further predictors of difficulty with mask ventilation include beard, obesity, no dentition/edentulous, and history of obstructive sleep apnea (OSA).
- In the event that a potentially difficult airway is identified, then consider expert consultation immediately.
- The usual size of endotracheal tube used is a #7.0 for adult women and #7.5 for adult men.
- Endotracheal tube size for children = (age/4) + 4.
  Children have a more superior and anterior larynx.
  The pediatric epiglottis can be larger and more “floppy”; therefore consider the use of a Miller (straight) blade.

G. Morrison
Keck School of Medicine of USC, Los Angeles, CA, USA

J. M. Tobin (✉)
Division of Trauma Anesthesiology, Keck School of Medicine of USC, Los Angeles, CA, USA
e-mail: Joshua.tobin@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_1

1.2 Equipment (Fig. 1.1)

- Endotracheal tube (ETT): usual size in women (#7), men (#7.5–8), and children (size = [age/4] + 4).
- Nasopharyngeal airway (NPA).
- Oropharyngeal airway (OPA).
- Laryngoscope: the two main types of laryngoscope blade are Macintosh (curved blade designed to be placed in the vallecula) and Miller (straight blade designed to manipulate the epiglottis).
- Gum elastic bougie.
- Bag valve mask (BVM) ventilator bag.
- Laryngeal mask airway (LMA): usual size for 70 kg adult = #4
- Magill forceps.
- Fiber-optic bronchoscope (FOB).

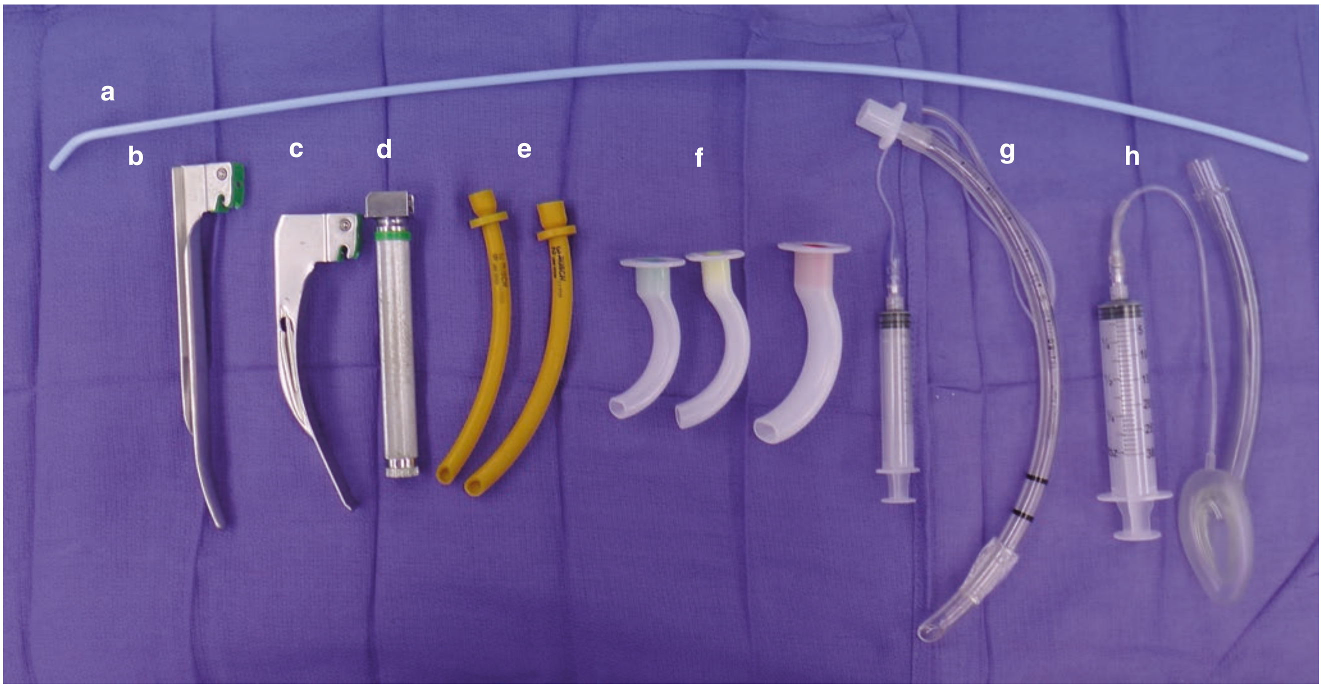


Fig. 1.1 Equipment setup: (**a**) gum elastic bougie, (**b**) Miller blade (straight), (**c**) Macintosh blade (curved), (**d**) laryngoscope handle, (**e**) nasopharyngeal airways (various sizes), (**f**) oral airways (various sizes), (**g**) oral endotracheal tube with stylet and syringe to fill cuff, (**h**) laryngeal mask airway with syringe to fill cuff

1.3 Technique

1.3.1 Positioning

- Sniffing position: to optimize laryngoscopy the neck is slightly flexed and the head extended to help align the oral, pharyngeal, and laryngeal axes. It helps to have the external auditory meatus and the sternum in the same horizontal plane.
- The patient should be positioned such that they are as close to the head of the bed as possible (i.e., close to the laryngoscopist).
- Bed height should be adjusted to the level of the laryngoscopist's xyphoid process to allow optimal visualization of the larynx.

1.3.2 Oropharyngeal Airway Management (Fig. 1.2a–c)

- Sized from the corner of the mouth to the ear or middle of the mouth to angle of mandible
- Normal adult size #7–9
- Placed gently in the airway; either approximating the gentle curvature of the oropharynx or inserting concave up (i.e., toward the nose) and gently rotating the OPA as it is inserted

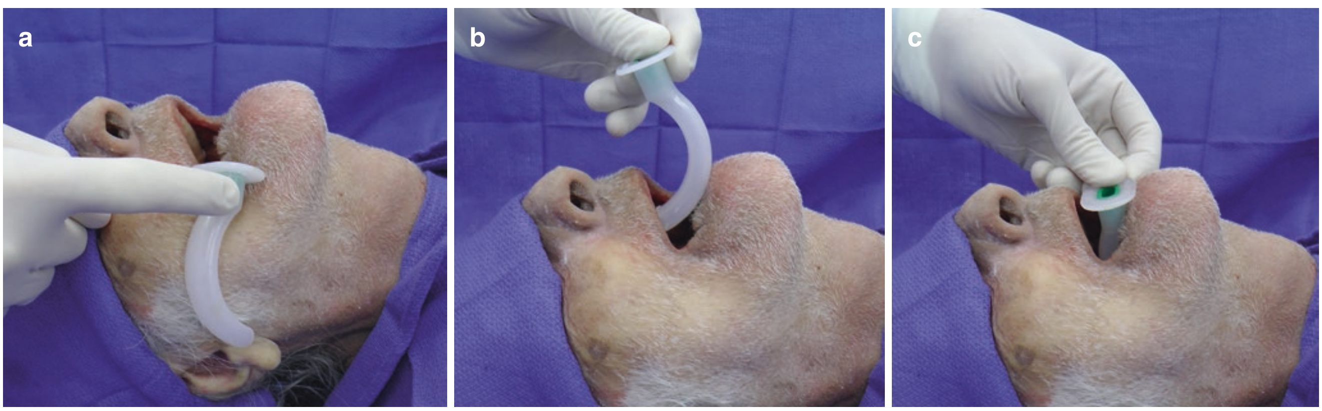


Fig. 1.2 Oropharyngeal airway management: (**a**) appropriate size is chosen by matching the length of the OPA from corner of the lip to angle of the mandible; (**b**) to insert OPA, first insert oral airway in "upside-down" position until halfway into the mouth, and then rotate 180 degrees as OPA is fully advanced into the mouth; (**c**) gently advance the OPA until the flange is at the lips

1.3.3 Nasopharyngeal Airway Management (Fig. 1.3a, b)

- Sized from tip of the nose to the earlobe.
- Normal adult size 28–32 French.
- Gently pass well-lubricated NPA via the larger of the two nares, being certain to pass the NPA along the gentle curvature of the nasopharynx rather than superiorly toward the turbinates.

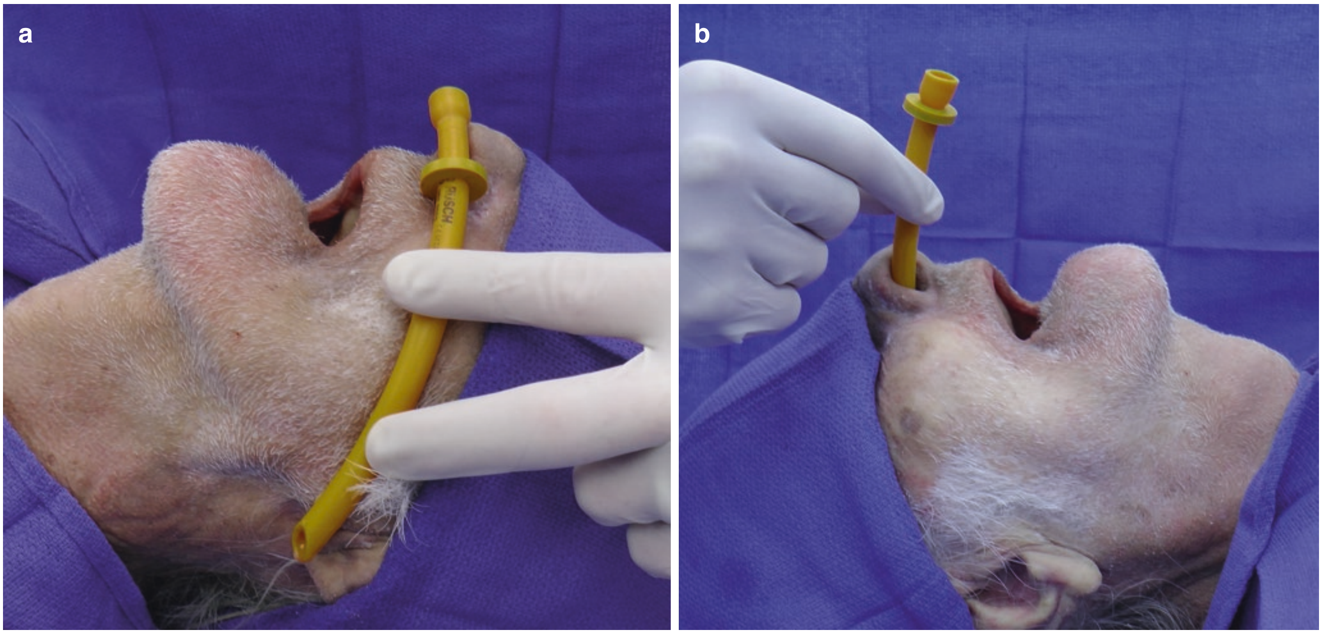


Fig. 1.3 Nasopharyngeal airway management: (**a**) appropriate size is chosen by measuring from tip of the nose to angle of the mandible. The largest diameter that will fit should be used; (**b**) insert NPA in posterior direction along floor of nasal cavity

1.3.4 Mask Ventilation

- The face mask should have a tight seal with good skin-face contact, such that oxygen from the BVM is directed only to the patient and does not leak to the environment.
- When mask ventilating patient, observe rise with each positive pressure breath delivered as well as “misting” (i.e., humid exhaled air) in the face mask during each exhalation.
- Assisted ventilation can be used to augment a patient’s tidal volume when the patient is still taking spontaneous pressure breaths. Assist each breath with positive pressure applied from the BVM.
- Hold the mask on the patient’s face with the “C-E hand position” (see Fig. 1.4a, b). With the middle, ring, and pinky fingers in the shape of an E, place fingers along the mandible to lift the jaw up and into the face mask. With the thumb and index finger in the shape of a C, hold the mask tightly sealed against the patient’s face. During spontaneous breathing, each time the patient initiates a breath, squeeze the BVM gently to augment the tidal volume. This is a useful technique if a patient is in respiratory distress and the laryngoscopist is pre-oxygenating while waiting for induction medications, airway equipment, etc.

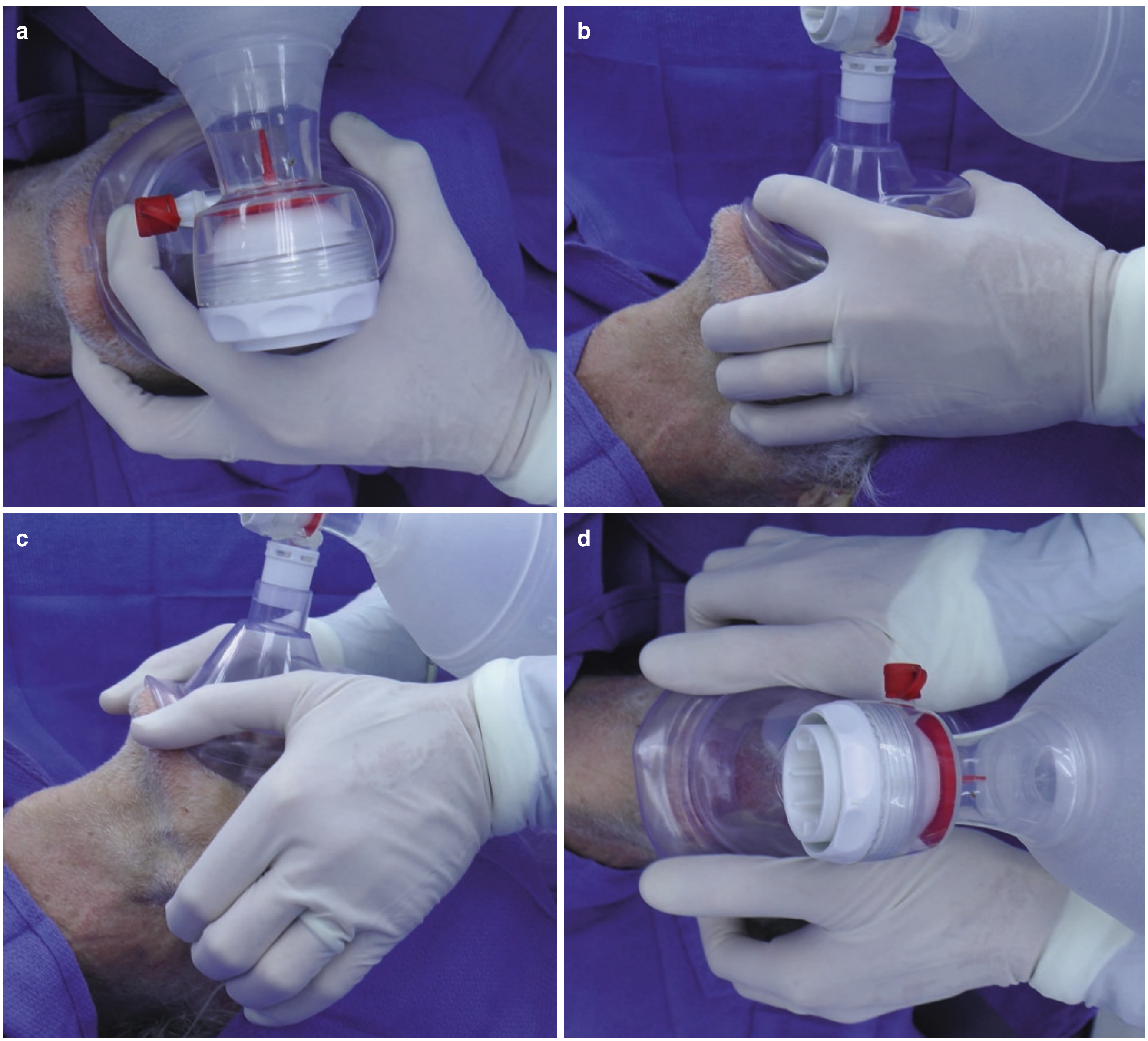


Fig. 1.4 Mask ventilation: (**a**) the “C-E clamp” (from above); (**b**) one-handed mask ventilation using the C-E clamp (lateral view). The “E” should lift the jaw up toward the mask, while the “C” maintains a tight seal between the face and the mask; (**c**, **d**) two-handed ventilation (view from above and lateral view)

1.3.5 One-Hand Ventilation (Fig. 1.4a, b)

- Most common method to ventilate patient.
- A tight seal is accomplished using the "C-E hand position" (as above).
- After induction, or once patient is no longer taking spontaneous respirations, the left hand holds the face and mask in the "C-E hand position," and the right hand squeezes the BVM to deliver the desired tidal volume. Ensure that, with each positive pressure breath given, adequate chest rise is seen and "misting" appears in face mask after each exhalation.

1.3.6 Two-Hand Ventilation (Fig. 1.4c, d)

- Technique requires two people and is utilized when the patient is difficult to ventilate using the one-hand technique. Two-hand ventilation allows laryngoscopist to apply tighter skin-face contact.
- One person performs jaw thrust using fingers on either side of the mandible with the thumbs providing a tight seal with the face mask. The second person squeezes the BVM to deliver the desired tidal volume.

1.3.7 Direct Laryngoscopy (DL) (Fig. 1.5)

- Laryngoscopist looks directly at the patient's larynx to visualize the vocal cords and watch the endotracheal tube pass through the vocal cords.
- Patient must be positioned in a "sniffing position" such that the oral, pharyngeal, and laryngeal axes align as closely as possible. This is best accomplished by positioning the patient with the neck slightly flexed and the head slightly tilted backward/extended (i.e., as if the patient were "sniffing a flower").
- In the event that cervical spine clearance has not been obtained (i.e., there is a risk of potential spinal fracture or spinal cord injury), then minimize movement of the neck during intubation with manual in-line stabilization of the neck in a neutral position.
- The Macintosh blade is the most common blade used for direct laryngoscopy.
- Open the patient's mouth with the right hand using a "scissoring motion" (Fig. 1.6a) (i.e., apply gentle pressure to the lower incisors/premolars/jaw in order to open the mouth). Be certain that while opening the patient's mouth, the sniffing position is maintained. Avoid applying pressure to the incisors/jaw area (Fig. 1.6b), as this does not provide sufficient mouth opening to accommodate easy passage of the laryngoscope blade.
- Hold laryngoscope in the left hand, and use the Macintosh blade to sweep the patient's tongue from right to left, such that the tongue is displaced to the left side (Fig. 1.5a).
- Advance the Macintosh blade until tip of the blade is in vallecula.
- Lift laryngoscope to visualize vocal cords, being careful not to rotate the laryngoscope back onto patient's teeth.
- When vocal cords are visualized, pass endotracheal tube through the vocal cords. Do not interrupt visualization of the vocal cords until tube is visualized passing through cords.
- Once tip of ETT is through cords, have stylet removed by assistant and then advance tube to correct depth.
- Verify end-tidal carbon dioxide ($ETCO_2$) using either a side-stream analyzer or colorimetric device. Also verify bilateral breath sounds and absence of breath sounds over the epigastrium.

Fig. 1.5 Direct laryngoscopy: insert blade of laryngoscope along the right side of the mouth, sweeping the tongue to the left side of the mouth

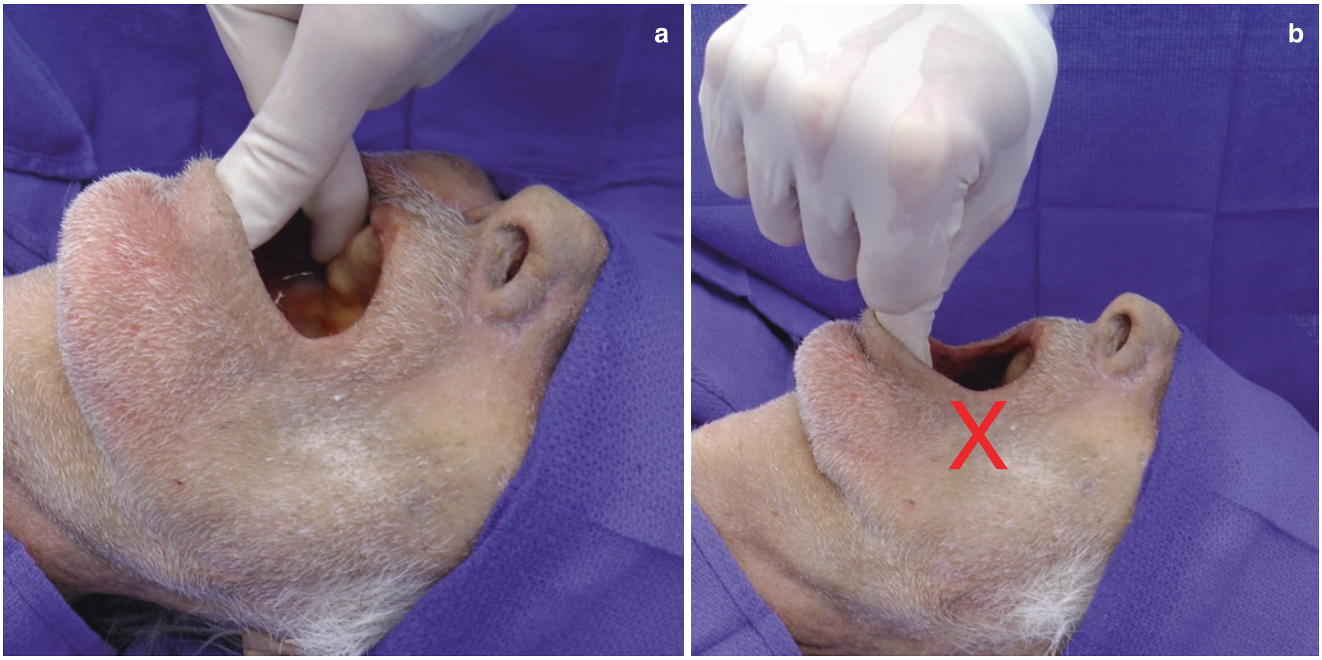


Fig. 1.6 Premolar push/scissoring the mouth open: (**a**) apply gentle pressure on premolars to open the mouth with a “scissoring” motion; (**b**) do not place digits on incisors to open the mouth

1.3.8 Bougie-Assisted Direct Laryngoscopy

- The bougie is useful during laryngoscopy if the laryngoscopist is unable to visualize the vocal cords during laryngoscopy.
- The tactile sensation of the bougie tip running along the tracheal rings (similar to a stick being run along a fence) gives the laryngoscopist tactile feedback that the bougie is within the trachea.
- Insert bougie into the mouth with angled coudé tip facing upward.
- The curved tip should contact the epiglottis as it is passed under the epiglottis and into the trachea. On insertion into the trachea, the bougie encounters the tracheal rings, which produce a distinct sensation to the laryngoscopist as the tip "runs over" individual rings. Once this feel is confirmed, the endotracheal tube can be inserted with confidence over the bougie to an appropriate depth; occasionally, and most commonly in cases of an anterior larynx, it may be necessary to rotate the tube gently to pass into the glottic opening without trauma. Some practitioners prefer to leave the laryngoscope in situ during endotracheal tube insertion to facilitate the procedure.
- Regardless of preference, the ETT is then passed over the bougie and into the trachea. Once the ETT is at an appropriate depth, the bougie is withdrawn.
- Verify $ETCO_2$ in the usual fashion.

1.3.9 Laryngeal Mask Airway (Fig. 1.7a–c)

- The laryngeal mask airway (LMA) is a supraglottic airway (i.e., it does not pass through the vocal cords). It is not a secure airway. Laryngospasm can obstruct airflow, such that it may not be possible to ventilate with the LMA.
- In the ICU, the LMA is best reserved as part of the emergency airway algorithm, for example, during "can't intubate, can't ventilate" cases or when urgent ventilation is required.
- LMA size is chosen base on patient's weight, and each LMA package will specify the weight for which the size is indicated. A typical size for a 70 kg adult is size #4.
- Open the patient's mouth by using the left hand to lift up the mandible. Ensure that the part of the LMA that will abut the hard palate is well lubricated prior to insertion.
- Hold the LMA in the right hand as shown (Fig. 1.7a), and use the index finger to guide the LMA along the hard palate and over the tongue (Fig. 1.7b). The LMA will "pop" into place as it passes the base of the tongue and is seated over the larynx (Fig. 1.7c).
- If the LMA is positioned correctly, one should be able to give positive pressure breaths, see chest rise, and hear minimal gas leak at 20 cm H_2O.
- Rescue technique:
  The LMA is useful in "can't intubate, can't ventilate" situations.
  Placement of an LMA may allow adequate gas exchange. If that is not possible, then surgical airway management with cricothyroidotomy is indicated.

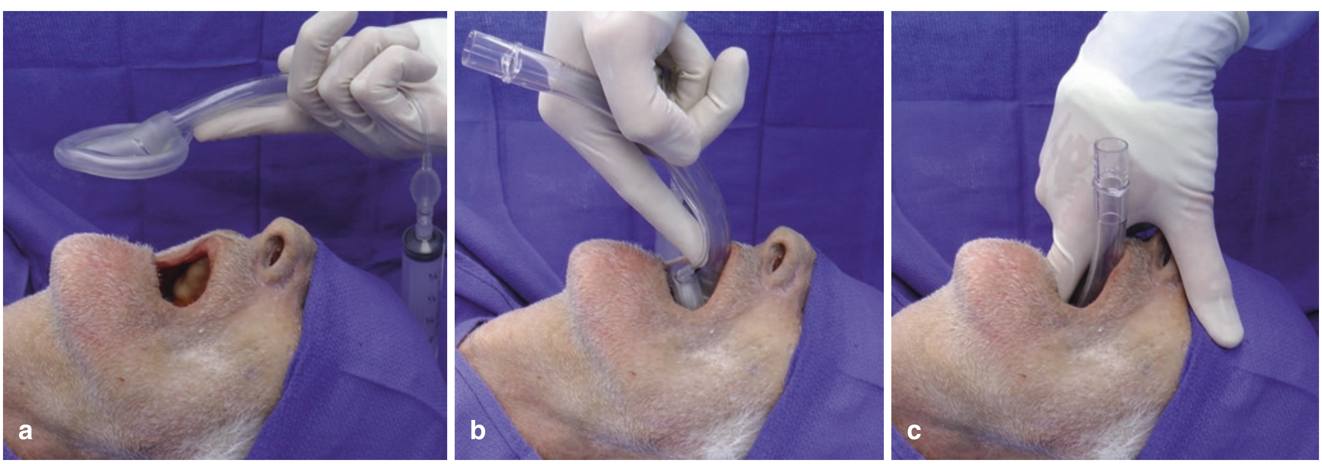


Fig. 1.7 LMA insertion: (**a**) hold LMA in the right hand as shown; (**b**) guide LMA along the roof of the mouth into the pharynx; (**c**) LMA will "pop" into place as it passes the base of the tongue and is seated over the larynx

1.3.10 Video Laryngoscopy (VL) (Figs. 1.8, 1.9, 1.10, 1.11, and 1.12)

- Video laryngoscopy is a method that uses a fiber-optic camera integral to a modified laryngoscope blade to indirectly visualize the glottis during endotracheal intubation.
- While video laryngoscopy does not improve the likelihood of intubation success on first-attempt in ICU patients compared to direct laryngoscopy, VL is a safe method to intubate patients with cervical spine injuries.
- The video laryngoscope is held in the left hand, and the scope is inserted into the mouth at the midline, without need to laterally displace the tongue with the scope.
- When the glottis is visualized on the screen, the styleted endotracheal tube is inserted through the mouth, and the video screen is used to guide the tube through the cords and into the trachea.
- Once tip of ETT is through cords, have the stylet removed by an assistant, and advance the ETT to the correct depth.
- Advantages of using the VL: it is unnecessary to align oral, pharyngeal, and laryngeal axes, which may be useful for patients with limited range of cervical motion.

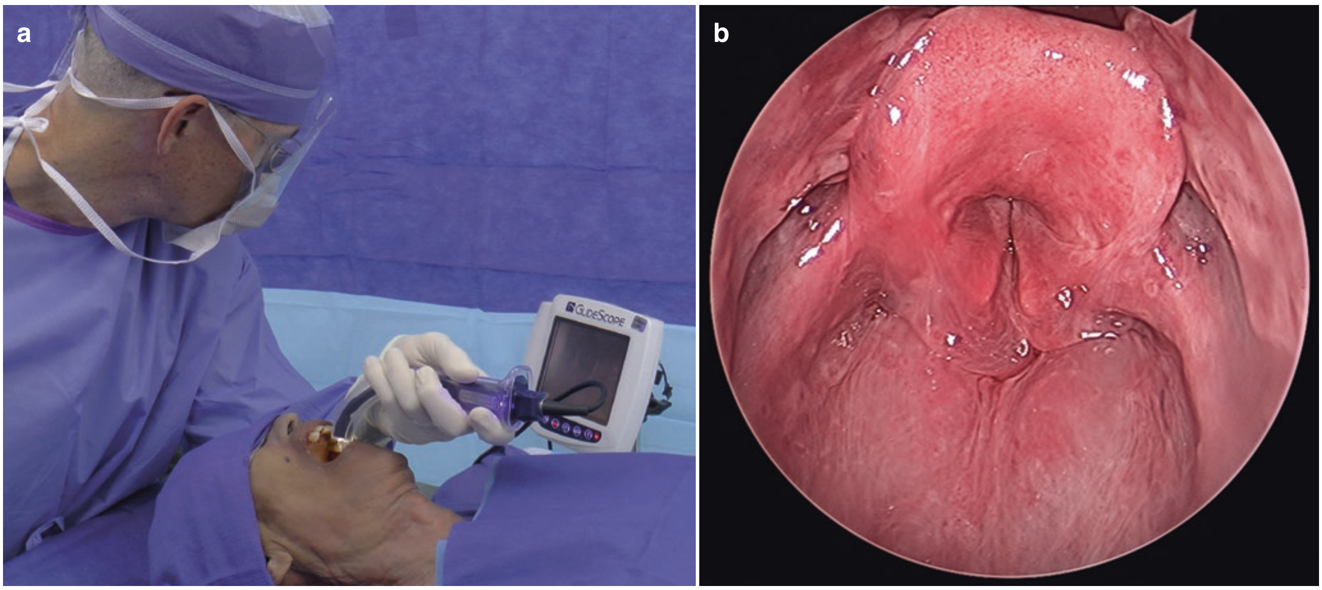


Fig. 1.8 The tip of the VL is inserted into the mouth; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

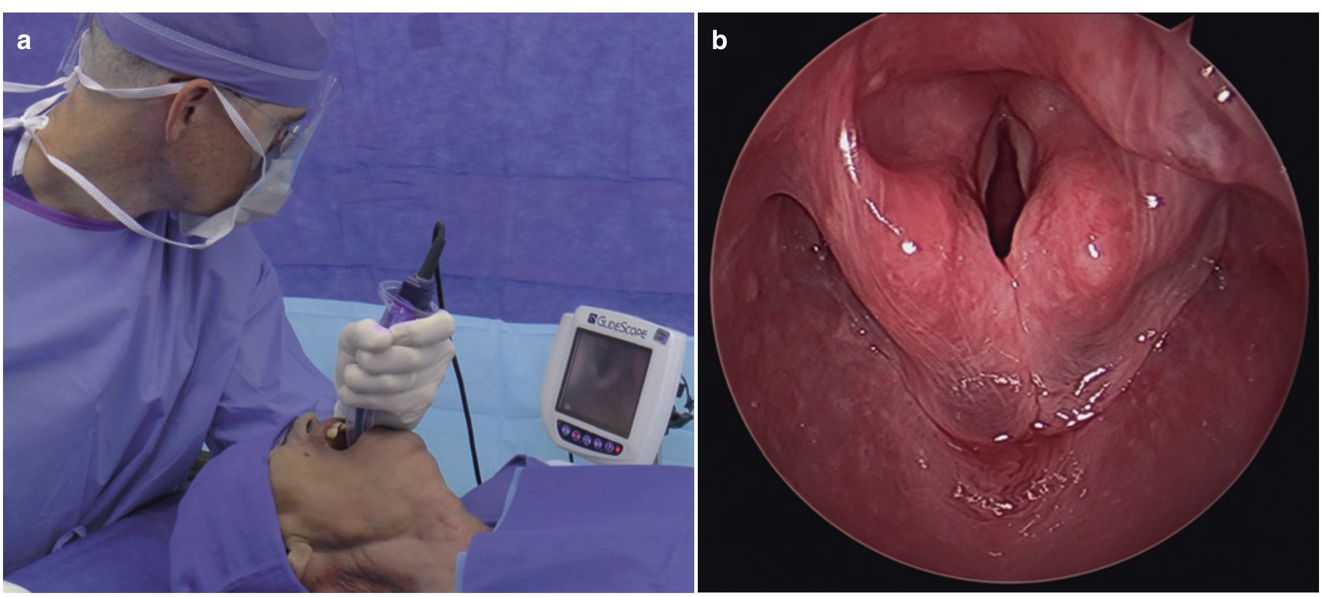


Fig. 1.9 The VL is inserted fully into the oropharynx, and the vocal cords are visualized; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

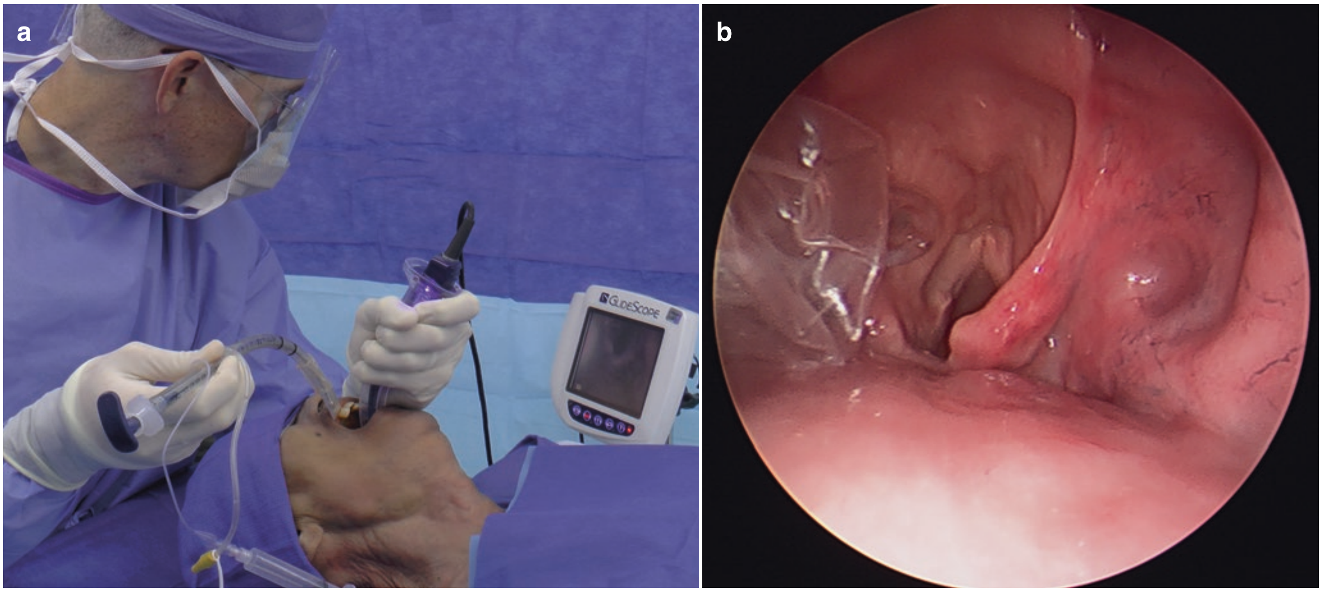


Fig. 1.10 A styleted endotracheal tube is inserted from the side while maintaining visualization of the vocal cords on the VL screen; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

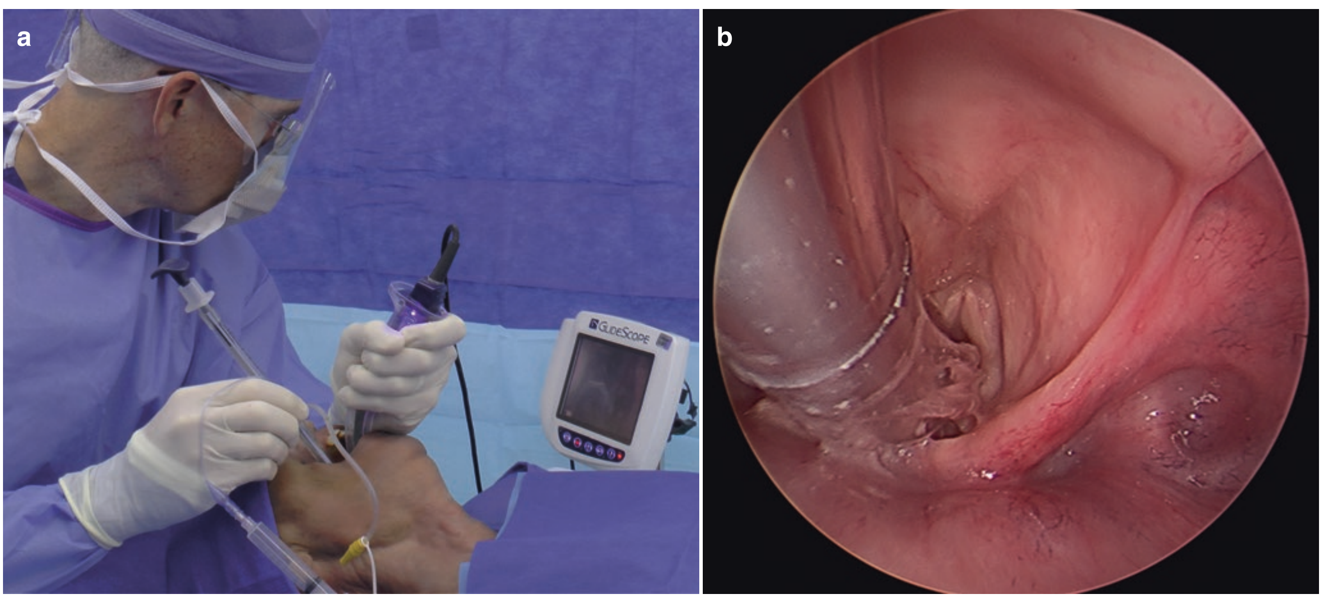


Fig. 1.11 The endotracheal tube is guided through the vocal cords and into the trachea; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

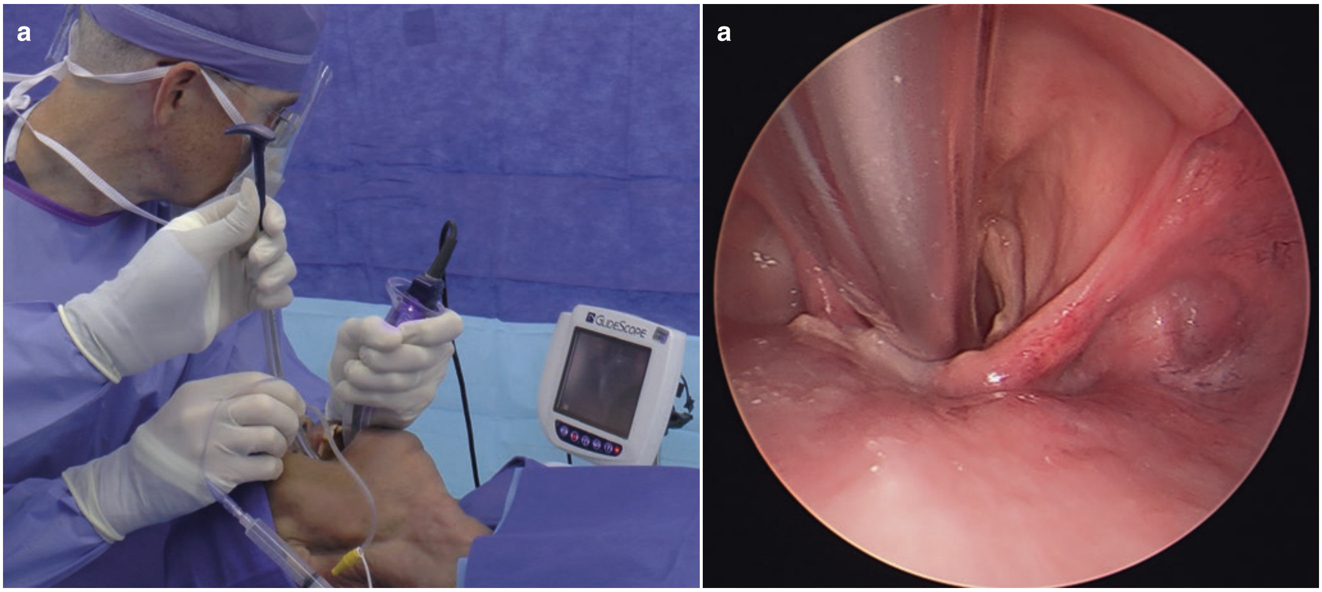


Fig. 1.12 An assistant removes the stylet, while the laryngoscopist holds the endotracheal tube; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

1.3.11 Nasal Intubation

- Indications for nasal intubation include patients in whom access to the oropharynx is limited (e.g., unable to open the mouth, jaw "wired shut", etc.).
- It is important to select the correct size for the nasoendotracheal tube (NETT), as the diameter of the NETT is proportional to its length. The curvature of the NETT is designed to accommodate the nasopharynx but can also limit its depth of insertion.
- Prior to nasal intubation, the nares should be treated with a topical vasoconstrictor (e.g., phenylephrine) to reduce bleeding. The nasal passage should also be lubricated and can be dilated with a nasopharyngeal airway prior to insertion of nasal endotracheal tube.
- The NETT should be warmed/softened prior to use. This can be accomplished by immersing the NETT in warm saline for several minutes prior to use.
- The NETT should then be well lubricated to minimize trauma to the nasal mucosa while being inserted.

1.3.11.1 Technique

- After preparing the nasopharynx as described above, insert NETT into nares. With gentle pressure, direct the tube in a posterior inferior direction along the floor of the nasal cavity toward the pharynx (Fig. 1.13). If resistance is met, then gentle rotation of the tube and redirection can facilitate passing the NETT.
- Continue passing tube until the natural bend in the NETT is at the tip of the nose.
- One can "blindly" pass the NETT, as the NETT will sometimes naturally enter the trachea rather than the esophagus. This must be confirmed with an $ETCO_2$ detector in the usual fashion.
- Alternatively, the NETT can be passed until it remains just above the vocal cords (as evidenced by audible respirations and humid expirium/mist in the NETT). The FOB can then be passed through the NETT. Commonly the vocal cords will be visualized just beyond the end of the NETT.
- Using slow gentle movements, pass the FOB through the vocal cords, enter the trachea, and advance the FOB until the carina is visualized. The NETT is then gently passed over the FOB, and the FOB is withdrawn.
- $ETCO_2$ is confirmed in the usual fashion.
- A final alternative is to insert NETT as above, but after the NETT is approximately halfway inserted, perform either VL or DL.
- Use Magill forceps to grasp the NETT that is now in the posterior pharynx, being careful to avoid touching/damaging the balloon. Thread the tip of NETT through the vocal cords.

1.3.12 Tips and Pitfalls

- n.b.: Do not use a NPA in cases of expected skull base fracture!
- n.b.: False-positive ET CO_2 values can be noted in the first 2–3 breaths after endotracheal intubation if there are carbonated beverages in the stomach!
- n.b.: Children may have a larger and more "floppy" epiglottis; therefore, consider the use of a Miller (straight) blade!
- n.b.: If there is any doubt regarding possible cervical spine injury, then use manual in-line stabilization!
- n.b.: Always have a backup plan; remember that any needed airway equipment must be within arm's reach!

Fig. 1.13 With gentle pressure, direct the NETT along the floor of the nasal cavity toward the pharynx

2 Percutaneous Tracheostomy

Morgan Schellenberg and Kenji Inaba

2.1 Surgical Anatomy

- Please refer to Chapter 3, Open Tracheostomy, Surgical Anatomy.

2.2 General Principles

- Tracheostomy is a bedside procedure performed in the intensive care unit for patients requiring prolonged mechanical ventilation or who require long-term airway protection. Specific indications include prolonged respiratory failure, high spinal cord injury, traumatic brain injury, and stroke. Tracheostomies can also be required as an adjunct for tracheal injuries, but these are typically performed in the operating room using the open technique.
- Tracheostomy can be performed using an open or percutaneous technique. Although both techniques can be considered in the majority of clinical situations, percutaneous tracheostomy is relatively contraindicated in patients with cervical spine fractures, patients on systemic anticoagulation, and patients with altered anatomy due to obesity, previous neck surgery, or radiation.
- Percutaneous tracheostomy requires the concurrent use of bronchoscopy and therefore cannot be performed if bronchoscopy is unavailable. Note that percutaneous tracheostomy requires three healthcare providers: the operator, the bronchoscopist, and a circulator.
- When compared to open tracheostomy performed in the operating room (OR), the benefits of percutaneous tracheostomy include lower cost, the lack of need to transport patients, and the avoidance of OR resource consumption.

M. Schellenberg · K. Inaba (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: kinaba@surgery.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_2

2.3 Patient Positioning

- The patient should be positioned with the neck fully extended in order to bring the trachea into the anterior position (Fig. 2.1). A roll should be placed behind the patient's shoulders to facilitate this, and the head can be stabilized with the use of a ring cushion.

Fig. 2.1 Patient positioning and draping for percutaneous tracheostomy. If the cervical spine has been cleared, the neck should be fully extended to bring the trachea into the anterior position. The entire neck, including the lower aspect of the mandible and upper chest, should be exposed, prepped, and draped

- The entire neck, including the lower aspect of the mandible and upper chest, should be exposed, prepped, and draped (Fig. 2.1) to provide adequate room to work and facilitate surface landmark identification.

2.4 Special Instruments

- The percutaneous technique can be performed with a variety of commercially available kits, which include a scalpel, catheter over hollow-bore needle, syringe, guidewire, guiding catheter, dilators, and introducers for the tracheostomy tube (Fig. 2.2). We prefer a single dilation system.
- A range of tracheostomy tube sizes should be available. We typically place a 6.0–7.0 mm internal diameter (ID) tube for women and a 7.0–8.0 mm ID tube for men. Tubes with a proximal extension should be considered for patients with thick or full necks, and a distal extension can also be used if required.
- Once the appropriately sized tracheostomy tube has been selected, it should be pre-loaded over the correspondingly sized tracheostomy loading dilator provided in the kit. Before beginning the procedure, ensure the tracheostomy tube cuff is intact by inflating it with air.
- The necessary equipment to convert to open tracheostomy (refer to Chapter 3, Open Tracheostomy) should be available at the bedside.
- Bronchoscopy equipment and a second physician to operate the bronchoscope are essential. A video bronchoscope setup allows the operator to view the procedure as well and is highly recommended.
- The patient must have an endotracheal tube in place that is at least 7.5 mm ID to allow for ventilation to occur around the bronchoscope during the procedure.
- A suction catheter for the tracheostomy, appropriate lighting, and an end-tidal CO_2 detector should be available.

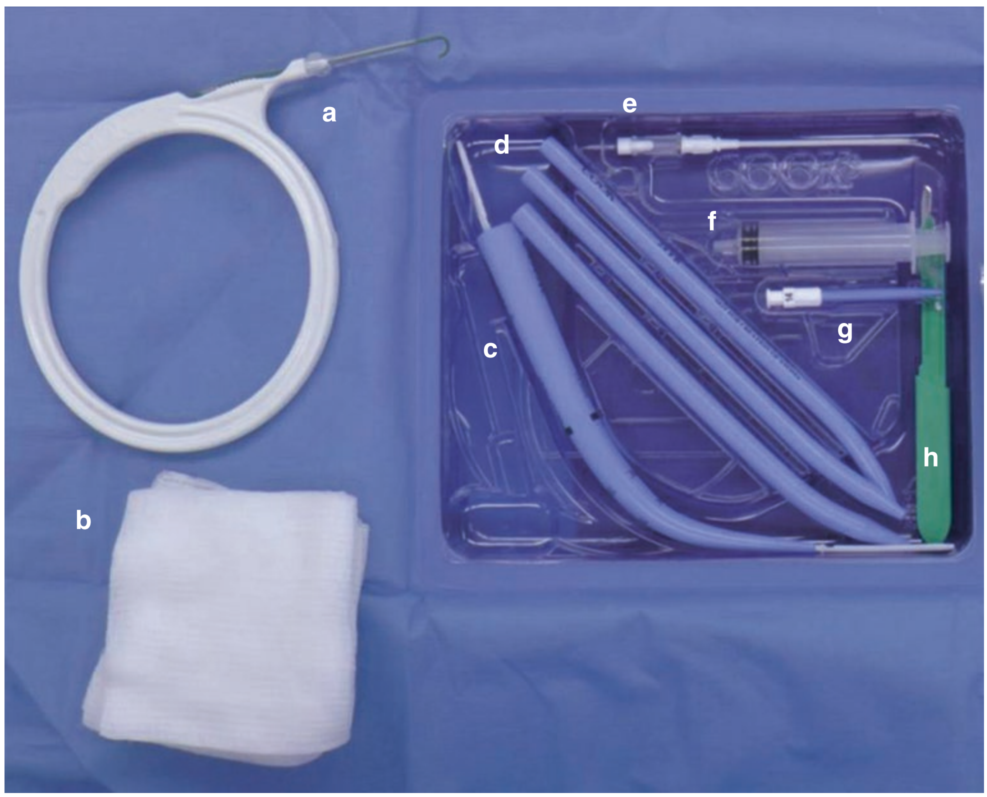


Fig. 2.2 Commercially available percutaneous tracheostomy kit. a, Guidewire. b, Gauze. c, Percutaneous tracheostomy dilator (*blue*) with guiding catheter (*white*). d, Tracheostomy loading dilators (3). e, Catheter over hollow-bore needle. f, Syringe. g, 14 Fr dilator. h, Scalpel

2.5 Technique

- The percutaneous technique begins in the same manner as the open technique. Start by identifying the thyroid cartilage, cricoid cartilage, and sternal notch (refer to Chapter 3, Open Tracheostomy). Use a 15 blade to make a 2–3 cm transverse incision through the skin approximately 2 fingerbreadths above the sternal notch, centered in the midline (Fig. 2.3a).
- Palpate the trachea deep to the subcutaneous tissue through the skin incision created. Use gentle blunt dissection with a Kelly clamp to dissect down onto the anterior surface of the trachea (Fig. 2.3b), and locate the second and third tracheal rings.
- Insert the bronchoscope through the endotracheal tube, and withdraw the endotracheal tube until it is located immediately proximal to the planned site of entry into the trachea. The operator can ballot the planned site of tracheostomy to help visualize this area.
- Use the catheter over a hollow-bore needle connected to a syringe filled with normal saline, and insert this into the airway through the skin incision at a 45 degree angle, pointed toward the carina. Entry into the airway will be both felt as a loss of resistance and visualized through the bronchoscope (Fig. 2.3c). Air can also be aspirated once within the trachea (Fig. 2.3d), providing a third means of confirming entry into the airway.
- The needle should be inserted into the trachea in the midline, represented by the 12 o'clock position when visualized through the bronchoscope. This prevents eccentric placement and helps avoid injury to the back wall of the trachea.
- Ensure the needle does not injure the bronchoscope when it is introduced into the trachea. The endotracheal tube should shield the bronchoscope and may need to be slowly retracted by the bronchoscopist.
- Under direct vision with the bronchoscope, remove the syringe and needle, leaving the catheter in place in the airway. Feed the guidewire into the airway through the catheter (Figs. 2.4 and 2.5a). Ensure bronchoscopically that the wire passes toward the carina and not upward to the larynx. Once the wire is in the trachea, remove the catheter.
- Next, use the serial dilators in the kit to widen the opening into the trachea. The 4.5-cm-long 14 Fr dilator should first be advanced into the airway over the wire and visualized within the lumen of the trachea bronchoscopically (Fig. 2.5b). After this, use the single size percutaneous tracheostomy dilator with the guiding catheter positioned within it to dilate the opening further (Fig. 2.5c). Use the image through the bronchoscope to do this under direct visualization throughout to ensure the posterior tracheal wall is not damaged (Fig. 2.5d).
- Remove the dilator but leave the guiding catheter over the wire, positioned in the airway (Fig. 2.5e). Insert the tracheostomy tube, preloaded over the appropriately sized tracheostomy loading dilator, over the guiding catheter and wire into the airway (Fig. 2.5f, g). The tube should be initially inserted straight back into the tracheal lumen and then directed toward the carina to pass it completely into the airway. Visualize the insertion with the bronchoscope.
- Remove the wire, guiding catheter, and tracheostomy loading dilator together. Inflate the cuff of the tracheostomy tube and suction out any secretions from the airway. Commence ventilation through the tracheostomy, and remove the endotracheal tube. Finally, suture the tracheostomy to the skin in four quadrants using 0 prolene suture (see Chapter 3, Open Tracheostomy).

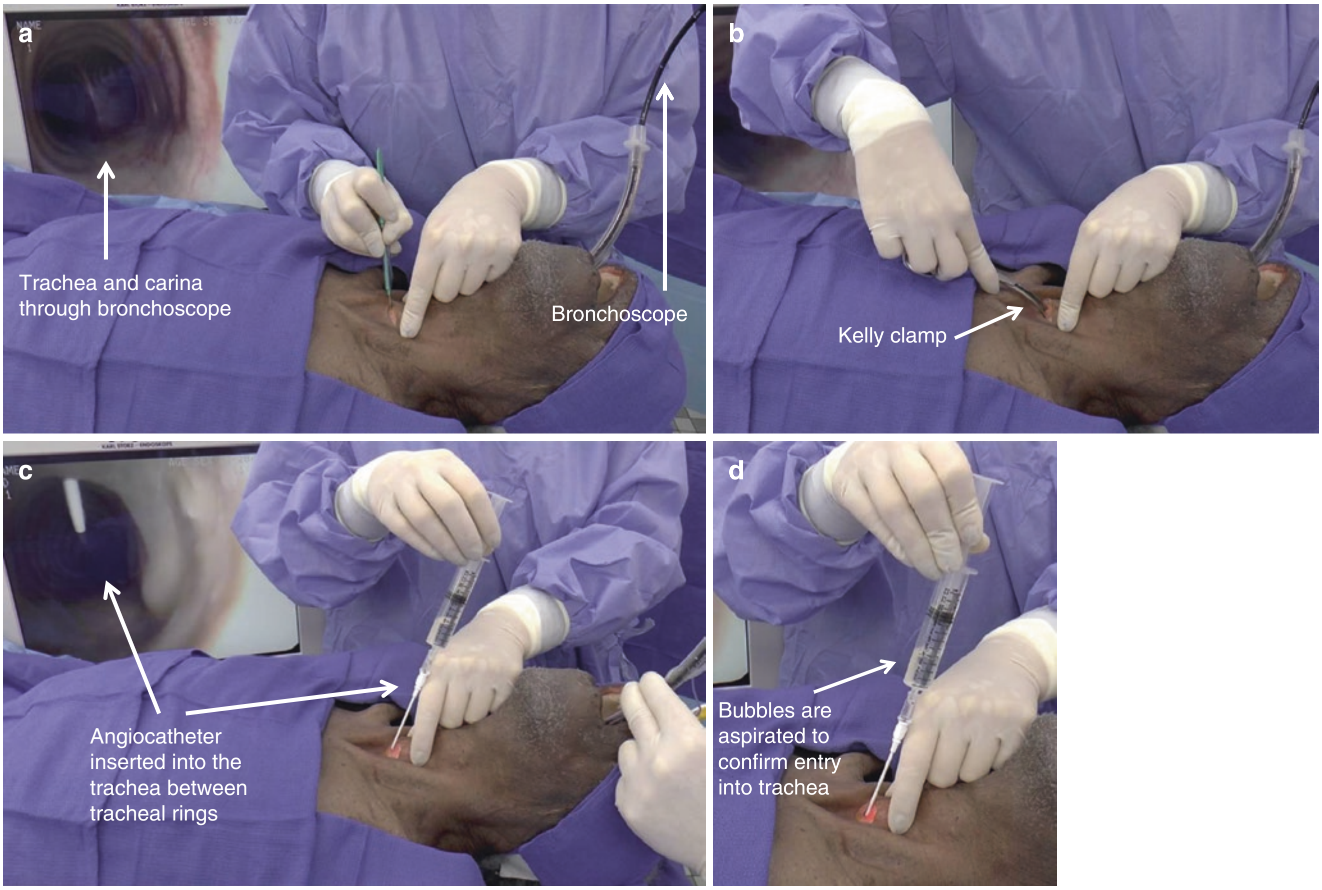


Fig. 2.3 (**a**–**d**) Steps of the percutaneous tracheostomy technique. Identify the thyroid cartilage, cricoid cartilage, and sternal notch. Use a 15-blade to make a 2-3 cm transverse skin incision in the midline, approximately 2 fingerbreadths above the sternal notch (**a**). Dissect down onto the anterior surface of the trachea (**b**), and locate the second and third tracheal rings. Insert the bronchoscope through the endotracheal tube and withdraw the endotracheal tube until it is located immediately proximal to the planned site of entry into the trachea. Use the catheter over a hollow-bore needle connected to a syringe filled with normal saline and insert this into the airway through the skin incision at a 45° angle, pointed towards the carina. Entry into the airway will be both felt as a loss of resistance and visualized through the bronchoscope (**c**). Air can also be aspirated once within the trachea (**d**)

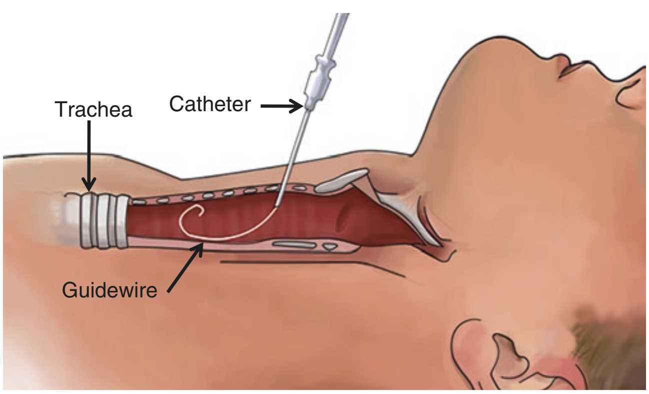


Fig. 2.4 Sagittal view of the airway during percutaneous tracheostomy. Through the catheter in the trachea, feed the guidewire into the airway towards the carina

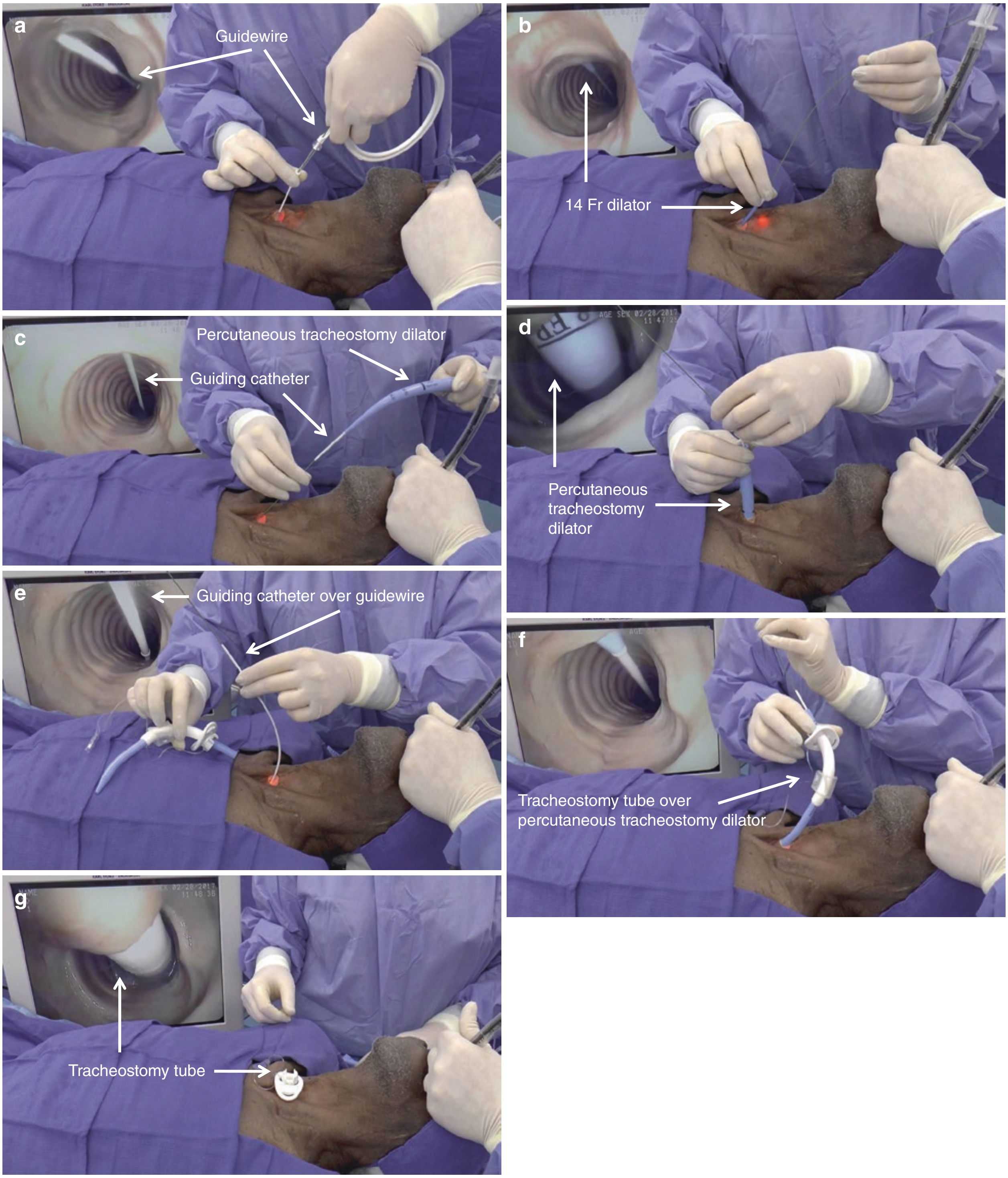


Fig. 2.5 (**a**–**g**) Under direct vision with the bronchoscope, remove the syringe and needle, leaving the catheter in place in the airway. Feed the guidewire into the airway through the catheter (**a**). Ensure bronchoscopically that the wire passes towards the carina and not upwards to the larynx. Once the wire is in the trachea, remove the catheter. Next, use the serial dilators in the kit to widen the opening into the trachea. The 4.5 cm-long 14 Fr dilator should first be advanced into the airway over the wire, and visualized within the lumen of the trachea bronchoscopically (**b**). After this, use the single size percutaneous tracheostomy dilator with the guiding catheter positioned within it to dilate the opening further (**c**). Use the image through the bronchoscope to do this under direct visualization throughout to ensure the posterior tracheal wall is not damaged (**d**). Remove the dilator but leave the guiding catheter over the wire, positioned in the airway (**e**). Insert the tracheostomy tube, preloaded over the appropriately sized tracheostomy loading dilator, over the guiding catheter and wire into the airway (**f**–**g**). Visualize the insertion with the bronchoscope. Remove the wire, guiding catheter, and tracheostomy loading dilator. Inflate the cuff of the tracheostomy tube and suction out any secretions from the airway. Commence ventilation through the tracheostomy and remove the endotracheal tube. Finally, suture the tracheostomy to the skin in four quadrants using 0 prolene suture (see Chapter 3, Open Tracheostomy)

2.6 Tips and Pitfalls

- The selection of the open versus percutaneous technique should be made according to the physician's skill set, the availability of bronchoscopy, and the patient's anatomy and injuries.
- To avoid passage of the tube into the subcutaneous tissues instead of the airway, direct bronchoscopic control to confirm entry into the trachea is mandatory.
- Posterior tracheal perforation is a serious complication as it can result in esophageal injury. Avoid this by halting the advancement of the needle in the percutaneous technique once air is aspirated and by visualizing the entry of the needle into the airway through the bronchoscope. All insertion steps must be done under direct visualization.
- When dilating the opening in the trachea over the guidewire, ensure the guiding catheter remains static relative to the dilator when inserting it into the trachea. This will allow the dilator to insert easily into the airway.
- For further tips and pitfalls, please refer to Chapter 3, Open Tracheostomy.

3 Open Tracheostomy

Morgan Schellenberg and Kenji Inaba

3.1 Surgical Anatomy

- The trachea is about 10–12 cm long and 2–2.5 cm wide. It extends from below the cricoid cartilage at the level of C6 to the bifurcation of the trachea into primary bronchi at the level of T4 (Fig. 3.1).
- It is comprised of 16–20 C-shaped cartilaginous rings that are deficient posteriorly to form the membraneous trachea, which allows for the expansion of the esophagus as a food bolus passes.
- The cervical trachea is bordered superiorly by the cricoid cartilage, inferiorly by the sternal notch, laterally and superficially by the paired strap muscles, and posteriorly by the esophagus. The recurrent laryngeal nerves and common carotid arteries are also located immediately lateral to the trachea.
- The thyroid isthmus lies anterior to the trachea at its origin below the cricoid cartilage, typically lying over the second and third tracheal rings.
- The trachea can be easily identified in most patients by first identifying the thyroid cartilage in the midline by palpation or visualization of the thyroid notch. The cricoid cartilage is the structure located inferior to this, and the trachea begins immediately caudal to the cricoid cartilage in the midline.

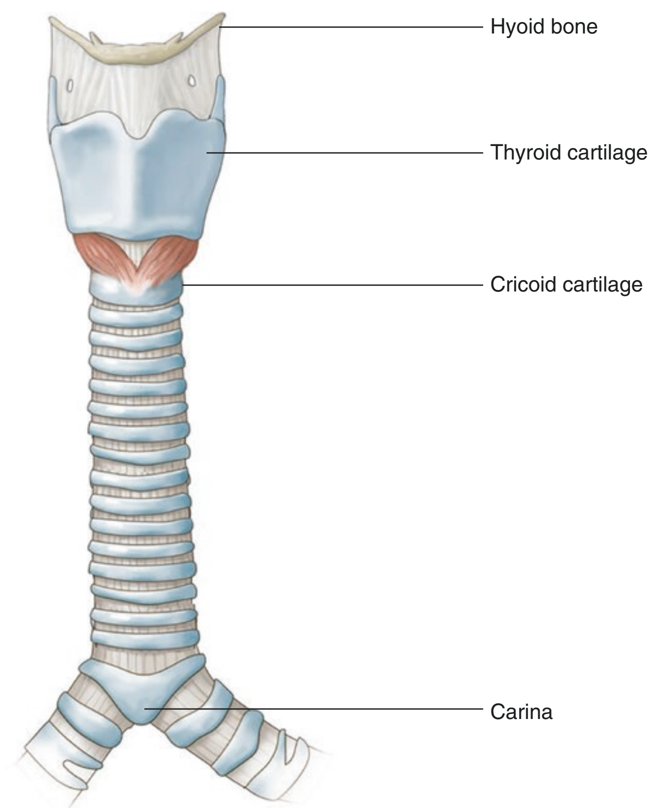


Fig. 3.1 Anatomy of the Larynx and Trachea

M. Schellenberg · K. Inaba (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: kinaba@surgery.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_3

3.2 General Principles

- Tracheostomy can be performed using an open or percutaneous technique. Although both techniques can be considered in the majority of clinical situations, open tracheostomy is preferred in patients with cervical spine fractures where the neck cannot be extended; in obese patients, where the anatomy may be obscured due to body habitus; in patients on systemic anticoagulation that cannot be held; and in patients among whom the anatomy may be altered by previous neck surgery or radiation.
- Most surgeons consider cricothyroidotomy to be the emergency surgical airway of choice. Tracheostomy is typically reserved for when a non-urgent long-term surgical airway is required or as part of a complex repair of a tracheal injury.
- For the indications for tracheostomy, please refer to Chapter 2: Percutaneous Tracheostomy.

3.3 Patient Positioning

- If there is no cervical spine injury, place a shoulder roll underneath the upper back, and extend the neck. If there is concern for cervical spine injury, the head should be kept in neutral position, and no shoulder roll should be used.
- When draping, the upper drape should be clear in order to facilitate communication with the physician at the head of the bed who is monitoring the airway and withdrawing the endotracheal tube.

3.4 Special Instruments

- The open tracheostomy technique requires a scalpel, Weitlaner or Senn retractors, Kelly clamp, Metzenbaum scissors, forceps, tracheal hook, tracheal spreader, and right-angle dissector (Fig. 3.2). A 6.0–8.0 mm internal diameter (ID) tube is appropriate for most patients. Cautery is ideal; however, the procedure can be performed without it.
- Good lighting, regular suction as well a suction catheter for the airway, and an end-tidal CO2 detector should always be available.
- 0 prolene suture on a cutting needle should be available to secure the tracheostomy to the skin.
- Note that in the ICU, this is a four-person procedure: operator, assistant, a physician to monitor the airway and adjust the endotracheal tube, and a circulator.

Fig. 3.2 Open Tracheostomy Instruments. (**a**) Debakey forceps, (**b**) suture scissors, (**c**) Wietlaner retractor, (**d**) tracheal hook, (**e**) needle driver, (**f**) Adson forceps, (**g**) 10 cc syringe, (**h**) tracheostomy tube, (**i**) obturator, (**j**) inner cannula, (**k**) Metzenbaum scissors, (**l**) right angle dissector, (**m**) tracheal spreader, (**n**) Kelly clamp, (**o**) Senn retractors, (**p**) scalpel

3.5 Technique

- After positioning and draping the patient as described, begin by identifying the relevant anatomy. In particular, locate the thyroid notch, cricoid cartilage, and the sternal notch (Fig. 3.3).
- Before proceeding further, check the tracheostomy tube to ensure that the proper size has been selected, the cuff is intact, and the obturator is loaded within the tube (Fig. 3.4).
- Use a 15 blade to make a 2–3 cm transverse incision through the skin approximately two fingerbreadths above the sternal notch, centered in the midline (Fig. 3.5a). Cautery or a Kelly clamp is then used to raise subplatysmal flaps inferiorly and superiorly. Visualize the paired strap muscles, located anterior and lateral to the thyroid isthmus and the trachea (Fig. 3.5b).
- Split the strap muscles overlying the trachea, in a vertical direction, and retract the strap muscles laterally in order to expose the underlying thyroid isthmus and trachea. A Weitlaner retractor can be placed into the incision to provide exposure (Fig. 3.5c). Alternatively, Senn retractors can be used.
- Identify the origin of the trachea, immediately below the cricoid cartilage. Locate and avoid the thyroid isthmus, traveling anterior to the second and third tracheal rings (Fig. 3.5d). The thyroid isthmus can be retracted toward the head or divided between silk ties (Fig. 3.5e, f).
- The endotracheal tube must remain securely within the trachea until the tracheostomy is placed, in case complications ensue and continued ventilation through the endotracheal tube is required. Endotracheal tube management must be assigned to a specific person capable of intubating in case the airway is lost.
- Use a fresh 15 blade to incise the trachea between two consecutive rings in a transverse orientation. Typically, a tracheostomy is placed between the second and third or third and fourth tracheal rings. The trachea should be opened over a length of approximately 1 cm to allow for easy passage of the tube (Fig. 3.5g). Care must be taken not to incise the posterior tracheal wall.
- Once the tracheotomy has been created, suction any secretions that are present, and visualize the underlying endotracheal tube. Have the person monitoring the endotracheal tube at the head of the bed slowly withdraw the endotracheal tube until it is immediately proximal to the tracheotomy.
- The tracheotomy can then be dilated with the tracheal spreader. Alternatively, partial resection of a tracheal ring can be performed. Neither is absolutely necessary in all cases.
- Use one hand to retract the cricoid cartilage or proximal trachea upward with the tracheal hook to deliver the tracheotomy into the surgical field (Fig. 3.5h). Use the other hand to gently insert the tracheostomy tube into the airway, directed toward the carina. The tracheostomy tube should be inserted at a 90° angle to the trachea and then reoriented toward the carina once inside the trachea (Fig. 3.5i).
- Remove the obturator, and replace it with the inner cannula. Inflate the tracheostomy tube, and confirm the return of end-tidal CO2 before proceeding. If the cuff maintains its seal and CO2 is returned, the endotracheal tube can be fully withdrawn from the patient, and ventilation can commence through the trachea. Pass the airway suction catheter down the tracheostomy tube to remove any secretions that accumulated during the procedure. Use 0 prolene suture to secure the tracheostomy tube through the appliance to the skin in four quadrants (Fig. 3.5j).
- Keep the obturator at the patient's bedside in case the tracheostomy tube is inadvertently removed and emergent reinsertion is required.

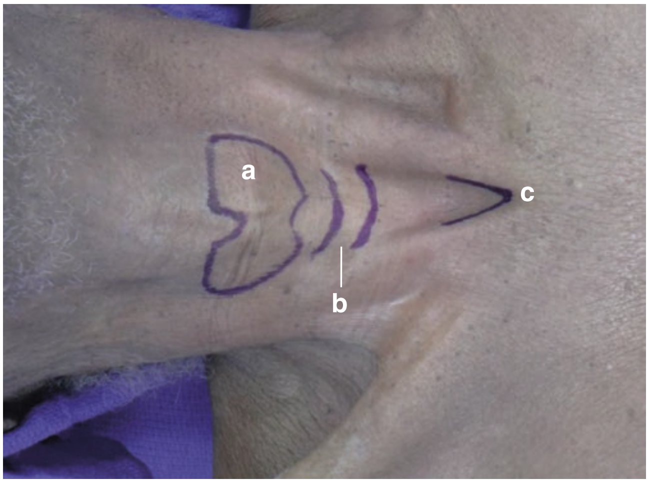


Fig. 3.3 Surface landmarks for Tracheostomy. (**a**) Thyroid cartilage, (**b**) Cricoid cartilage, (**c**) Sternal notch

Fig. 3.4 Preoperatively, check the tracheostomy tube to ensure that the cuff is intact and the obturator is loaded within the tube

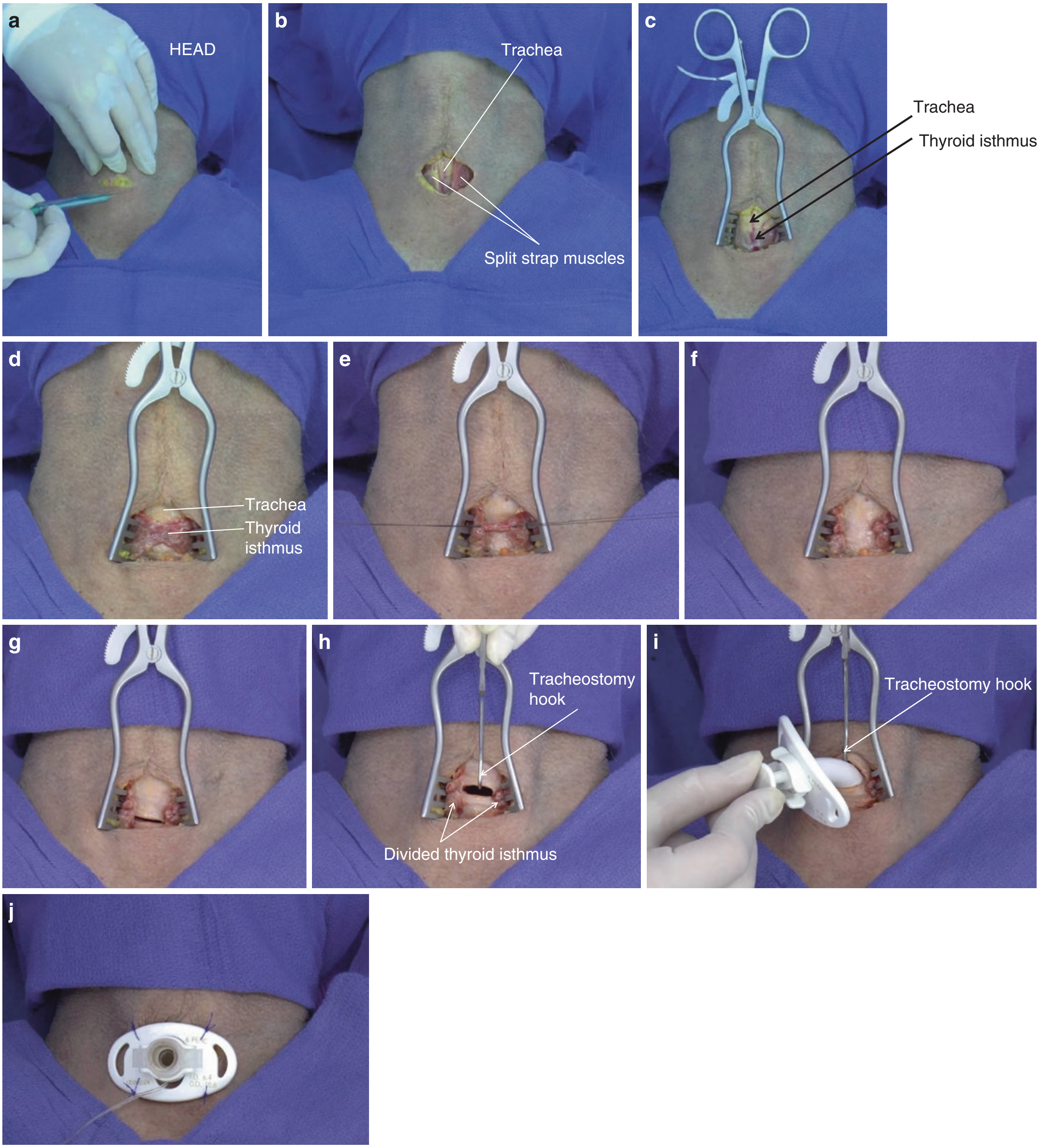


Fig. 3.5 (**a**–**f**) Steps of the Open Tracheostomy Technique. (**a**) Perform a 2–3 cm transverse incision through the skin, approximately two fingerbreadths above the sternal notch. (**b**) Raise subplatysmal flaps inferiorly and superiorly and visualize the paired strap muscles, located anterior and lateral to the trachea. Split the strap muscles in the midline to expose the thyroid isthmus and trachea. (**c**) Placement of a Wietlaner retractor between the split strap muscles provides good expose of the underlying thyroid isthmus and trachea. (**d**) The thyroid isthmus is under the strap muscles, anterior to the second and third tracheal rings. If the isthmus is thin, it may be retracted towards the head to allow better exposure of the unerlying trachea. (**e**, **f**) If the thyroid isthmus is bulky and impedes access to the trachea, it can be divided between silk ties. (**g**) Division of the thyroid isthmus, exposure of the trachea and tracheotomy through the 2nd-3rd or 3rd -4th tracheal rings. (**h**) Retraction of upper edge of the tracheotomy upwards with the tracheal hook stabilizes the trachea and allows direct visualization of the tracheal lumen during insertion of the tracheostomy tube. (**i**) Insertion of the tracheostomy tube with the obturator in place. (**j**) Removal of the obturator and securing of the tracheostomy tube with four sutures to the skin. In addition, the tracheostomy appliance should be secured with ties placed through the two lateral holes and passed around the neck in order to reduce the risk of accidental tube dislodgement

3.6 Complications

- Complications of tracheostomy can be considered as early and late complications. Early complications occur within minutes to days after tracheostomy placement, while late complications occur after weeks to months.
- Early complications include bleeding, aspiration of blood, false passage, acute airway loss, and dislodgement.
  – False passage of the tracheostomy tube, wherein the tracheostomy tube is passed into the soft tissues of the neck instead of into the tracheal lumen, is a dreaded complication. This should be avoided by ensuring clear visualization of the anterior surface of the trachea and by using the tracheal hook to stabilize the trachea during insertion. The appliance should pass easily into the airway and should not be forced. If false passage does occur, it should immediately be detected by the lack of color change on the CO2 detector and by the absence of breath sounds on auscultation.
  – Acute airway loss during tracheostomy placement is another potentially catastrophic complication. As the oro−/nasotracheal tube cuff is deflated and the tube is withdrawn to allow passage of the tracheostomy tube, the airway can be lost completely. To avoid this, clear two-way communication between the physician managing the endotracheal tube from the head of the bed and the physician placing the tracheostomy is critical. The appropriate timing for endotracheal tube withdrawal must be specifically communicated and performed in a slow and controlled fashion.
  – Aspiration of blood can occur as a result of bleeding from the tracheostomy site. Routine in-line suctioning through the tracheostomy tube should be performed to clear the airway of any post-procedure blood. In more severe cases bronchoscopic suctioning may be needed.
  – Dislodgement of the tube is another feared complication of tracheostomy, especially in the early postoperative period. The obturator for the tracheostomy tube should be kept by the patient's bedside at all times. If dislodgement occurs, the obturator should be placed back into the lumen of the tracheostomy tube, and an attempt should be made to replace the tube through the tracheostomy site. It may help to extend the patient's neck prior to attempting this, in order to realign the soft tissues of the neck into the same configuration they were in during tracheostomy creation. Especially if dislodgement occurs soon after tracheostomy creation, this can be challenging. The fastest means of re-securing the airway is often to reintubate the patient orotracheally. To avoid dislodgment, routinely suturing the tracheostomy appliance in place should be performed in addition to the use of tracheostomy ties.
- Late complications include tracheoinnominate fistula (TIF) and tracheal stenosis.
  – TIF is a rare but highly lethal complication of tracheostomy in which fistulization occurs between the trachea and the innominate artery. Risk factors for TIF include tracheostomy placement below the second or third tracheal ring, high cuff pressures, anatomic deformities of the neck or chest, infection, radiation, steroids, and malnutrition. TIF is exceedingly rare in the first 48–72 h after tracheostomy placement and typically presents in the first several weeks after the procedure. In approximately half of cases, TIF presents with a sentinel bleed. These patients, who experience a self-limited and small volume bleed, should undergo CT angiogram as the investigation of choice to rule out a TIF if examination of the tracheal stoma and bronchoscopy do not reveal an obvious source of bleeding. Patients with large volume tracheal bleeding should be considered to have a TIF until proven otherwise and should not undergo imaging. Initial management of these patients consists of immediate hyperinflation of the tracheostomy tube cuff to tamponade the bleeding. If this is unsuccessful, a finger should be inserted into the peristomal soft tissues alongside the tracheostomy appliance to compress the innominate artery against the sternum. These two maneuvers will temporarily control the bleeding in the majority of cases. Patients must then be brought emergently to the operating room for median sternotomy, resection of the TIF, and ligation of the innominate artery. The tracheal defect is ideally closed primarily with overlying soft tissue coverage.
  – Tracheal stenosis can occur after prolonged tracheostomy. The most effective way of avoiding this complication is early decannulation. Tracheal stenosis can range from a benign, asymptomatic condition to a life threatening one, depending on the degree of airway narrowing. Treatment options include stenting, tracheal resection, and insertion of an extended tracheostomy tube to bypass the area of stenosis.

3.7 Post-Procedure Care

- After tracheostomy insertion, the skin site should be inspected and cleaned daily. Particularly in the acute post-procedure period, the incision should be monitored for bleeding or hematoma formation.

- Routine in-line suctioning with a soft catheter should be performed as needed to help clear secretions. It is important to use in-line suctioning to avoid introducing bacteria into the airway. The use of a soft catheter is also critical, in order to avoid trauma to the airway from repeated suctioning. This can induce bleeding and stimulate granulation tissue, which can in turn contribute to tracheal stenosis.
- The tracheostomy tube cuff should be kept inflated as long as the patient requires mechanical ventilation. Cuff pressures should not exceed 30 cm H_2O (23 mmHg). Once a patient has been off of mechanical ventilation for at least 24 h and secretions are minimal, the cuff should be deflated. If this is well tolerated for an additional 24 h, the physician can consider exchanging the cuffed tracheostomy tube for a cuffless tube.
- The appropriate timing for tracheostomy tube exchange is unclear. It is generally recommended to wait at least 7 days before downsizing.
- Decannulation should be considered when the patient has been weaned from the ventilator, secretions are minimal, the mental status allows for airway protection, and the patient is able to generate an effective cough. Prior to decannulation, the tracheostomy should be capped for at least 24 h, and the patient should be able to phonate and breathe without stridor. After decannulation, an occlusive dressing should be placed over the tracheostomy site as it heals by secondary intention.

3.8 Tips and Pitfalls

- To avoid passage of the tube into the subcutaneous tissues instead of the airway, utilize the tracheal hook to stabilize the trachea and directly visualize the passage of the tube into the airway.
- Avoid posterior tracheal perforation by taking care not to plunge the scalpel deeply through the trachea.
- Premature removal of the endotracheal tube is another potential pitfall during tracheostomy. The physician withdrawing the endotracheal tube during the procedure should do so slowly and cautiously. Equipment (direct or videoscopic laryngoscope and endotracheal tubes) should be at the bedside to reintubate the patient if necessary.
- The tracheostomy cuff can tear during insertion of the tube into the airway. Immediately after placing the tube, be sure to inject air into the cuff and confirm that it is able to maintain a seal. If not, the tube must be replaced.
- In the ICU, the obturator for the patient's tracheostomy should be kept at the bedside to facilitate reintroduction of the tracheostomy tube if it comes out. If this occurs, the patient's neck should be extended to reconfigure the anatomic alignment of the patient's neck when the tracheostomy was inserted. This allows the tracheostomy tract to straighten out and facilitates reintroduction of the tube. After the neck is extended, the obturator should be placed into the tracheostomy tube lumen, and the tube should be inserted back into the patient's trachea.

4 Cricothyroidotomy

Morgan Schellenberg and Demetrios Demetriades

4.1 Surgical Anatomy

- The major structures of the larynx are the hyoid bone, thyroid cartilage, and cricoid cartilage (Fig. 4.1), from cephalad to caudad.
- The cricoid cartilage is the only complete ring in the larynx and trachea. The hyoid bone, the thyroid cartilage, and all the tracheal rings are incomplete, and their posterior wall is membranous. The cricoid ring mechanically stents the airway open and is an important attachment point for muscles and ligaments.
- The cricothyroid space is located between the thyroid and cricoid cartilages. It is covered by the cricothyroid membrane and is bordered laterally by the paired cricothyroid muscles. In adults it is about 2–3 cm wide and about 1 cm in height. The cricothyroid muscles cover the lateral parts of the cricothyroid membrane, and therefore only the middle part of the membrane (approximately 1 cm in size in both the transverse and vertical directions) is directly under the skin, providing easy and direct access to the airway (Fig. 4.1).
- The vocal cords are located in the thyroid cartilage, about 1 cm from the upper border of the cricothyroid membrane. This proximity to the cricothyroid membrane puts the cords at risk of injury during a difficult cricothyrodotomy.

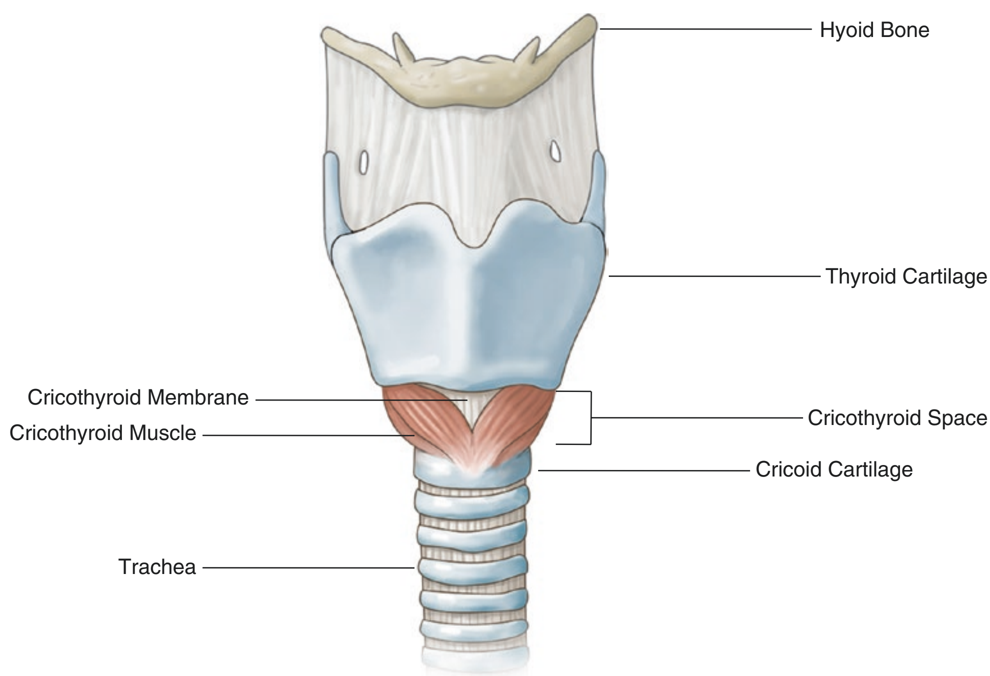


Fig. 4.1 Anatomy of the Larynx and Cricothyroid Space. Most of the space between the thyroid and cricoid cartilages is covered by the cricothyroid muscles. In the midline, the cricothyroid membrane is not covered by muscle and is the target for cricothyroidotomy

M. Schellenberg · D. Demetriades (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_4

4.2 General Principles

- Cricothyroidotomy is the surgical airway of choice in patients requiring an emergency airway after attempts at orotracheal or nasotracheal intubation have failed, if the patient cannot be oxygenated with alternative airway rescue techniques, such as the laryngeal mask airway. Severe maxillofacial trauma, large neck hematomas, laryngeal trauma, or laryngeal edema are common conditions requiring cricothyroidotomy.
- Cricothyroidotomy can be performed with an open or percutaneous technique.
- A relative contraindication to cricothyroidotomy is the pediatric patient, especially under 8 years of age, in whom the cricothyroid membrane is very small and the rate of long-term complications, such as stenosis, is high. In these patients, transtracheal needle jet ventilation (Chapter 5) is preferred. A second contraindication is patients with suspected tracheal transection distal to the cricothyroid space.
- Although some surgeons advocate for the routine conversion of a cricothyroidotomy into a formal tracheostomy, there is no evidence to support this practice, and the authors do not recommend it.

4.3 Special Instruments

- The open technique requires a scalpel, Senn retractors, Kelly clamp, Metzenbaum scissors, forceps, a tracheal hook, and a variety of sizes of endotracheal and tracheostomy tubes (Fig. 4.2).
- The percutaneous technique can be performed with a variety of commercially available kits (Fig. 4.3), which all include a scalpel, hollow-bore needle, syringe, wire, dilator, and the cricothyroidotomy tube.
- Suction, appropriate lighting, and an end-tidal CO2 detector should be available.

Fig. 4.2 Open cricothyroidotomy instruments. A, Debakey forceps. B, suture scissors. C, Wietlaner retractor. D, tracheal hook. E, needle driver. F, Adson forceps. G, 10 cc syringe. H, tracheostomy tube. I, obturator. J, inner cannula. K, Metzenbaum scissors. L, right angle dissector. M, tracheal spreader. N, Kelly clamp. O, Senn retractors. P, scalpel

Fig. 4.3 Commercial percutaneous cricothyroidotomy tray. A, sterile drape. B, 15-blade scalpel. C, percutaneous dilators. D, tracheal hook. E, tracheal spreader. F, cricothyroidotomy tube. G, 10 cc syringe. H, 11-blade scalpel. I, angiocatheter. J, ties to secure the cricothyroidotomy tube. K, guiding wire

4.4 Patient Positioning

- If the cervical spine has been cleared, the neck should be extended to bring the larynx anteriorly. If cervical spine precautions must be maintained, cricothyroidotomy can be performed with the neck in a neutral position.
- Identification of key landmarks using surface anatomy is critical and must be done rapidly before the procedure (Fig. 4.4). The thyroid notch is easily visualized or palpated in thin patients and provides a quick method of identifying the thyroid cartilage. Palpation immediately caudal to the thyroid cartilage in the midline identifies a soft area, which is the cricothyroid space and is the target for the cricothyroidotomy.
- In severe local trauma with a large hematoma or in obese patients, especially with a short and thick neck, external identification of the cricothyroid space is often difficult or not possible. In these cases, the four-finger technique can be used to identify the location of the cricothyroid space (Fig. 4.5). With the physician's four fingers extended side by side, the small finger of the hand is placed in the patient's sternal notch. The area below the physician's index finger then approximates the cricothyroid space in the midline.

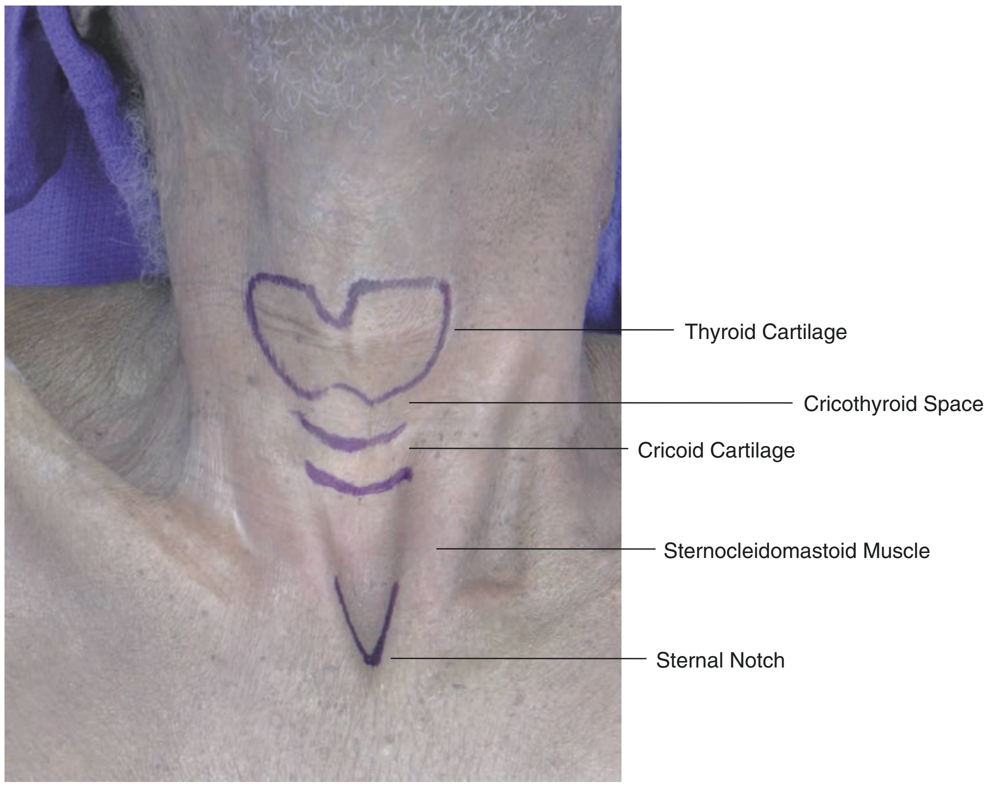


Fig. 4.4 Surface anatomy of the anterior neck, showing the thyroid cartilage, cricoid cartilage, and cricothyroid space. The soft space between the thyroid and cricoid cartilages is the cricothyroid membrane

Fig. 4.5 The four finger technique for landmarking the cricothyroid space. Place the tip of your fifth digit in the patient's sternal notch. Your index finger then indicates the location of the cricothyroid membrane and the site of your skin incision for cricothyroidotomy

4.5 Technique: Open Cricothyroidotomy

- Stabilize the thyroid cartilage with the non-dominant hand, between the index finger and thumb.
- Use the index finger and thumb stabilizing the thyroid cartilage to provide retraction on the skin. Make a vertical incision over the cricothyroid space, approximately 3 cm in length (Fig. 4.6a). A transverse incision over the cricothyroid space is an acceptable option. The vertical incision reduces the risk of accidental injury to the anterior jugular veins, which can complicate the procedure and result in aspiration of blood.
- Place Senn retractors into the skin incision, and visualize or palpate the underlying cricothyroid membrane in the midline (Fig. 4.6b). With the scalpel, divide the cricothyroid membrane in a transverse direction (Fig. 4.6c). Whenever possible, this should be done along the superior border of the cricoid cartilage, in order to avoid injuring the cricothyroid artery which courses through the superior part of the cricothyroid membrane.
- Place the tracheal hook in the superior aspect of the cricothyroidotomy, and lift upward and toward the patient's head (Fig. 4.6d). This serves to open the incision further, immobilize the larynx, and facilitate passage of the tube into the airway under direct vision.
- With the non-dominant hand on the tracheal hook and the dominant hand holding either an endotracheal or a tracheostomy tube, guide the tube into the airway directed toward the carina (Fig. 4.6e, f). If using a tracheostomy tube, ensure the obturator is in place within the tube during placement, and replace it with the inner cannula once the tube is in the airway.
- Inflate the cuff with 10 cc of air, and confirm proper placement within the airway, using a combination of end-tidal CO2 detection and physical exam (bilateral air entry on auscultation, etc.). Secure the tube with sutures and/or tracheal ties (Fig. 4.6g).

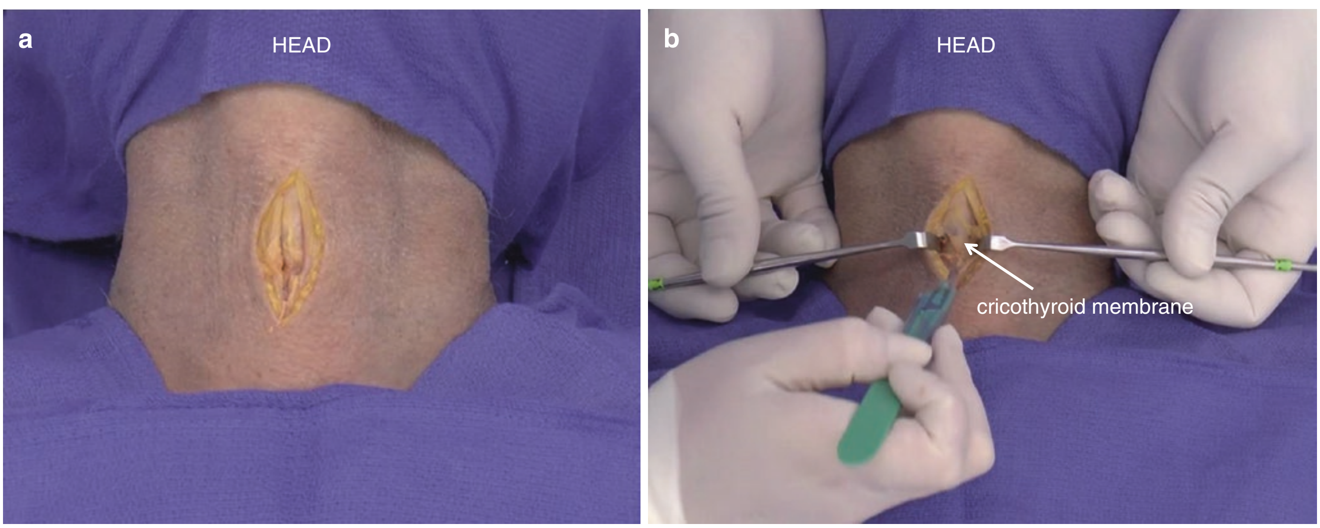


Fig. 4.6 (**a**–**g**) Steps of the open cricothyroidotomy technique. With the neck in neutral position or extended if the cervical spine has been cleared, stabilize the thyroid cartilage and create a 3 cm vertical incision in the skin and subcutaneous tissue overlying the cricothyroid membrane (**a**). Use Senn retractors to visualize the underlying cricothyroid membrane (**b**). Divide the cricothyroid membrane in a transverse direction (**c**). Place the tracheal hook in the proximal aspect of the cricothyroidotomy to deliver the airway into the surgical field (**d**). Insert the cricothyroidotomy tube or tracheostomy tube through the cricothyroidotomy (**e**, **f**) and secure it in place (**g**)

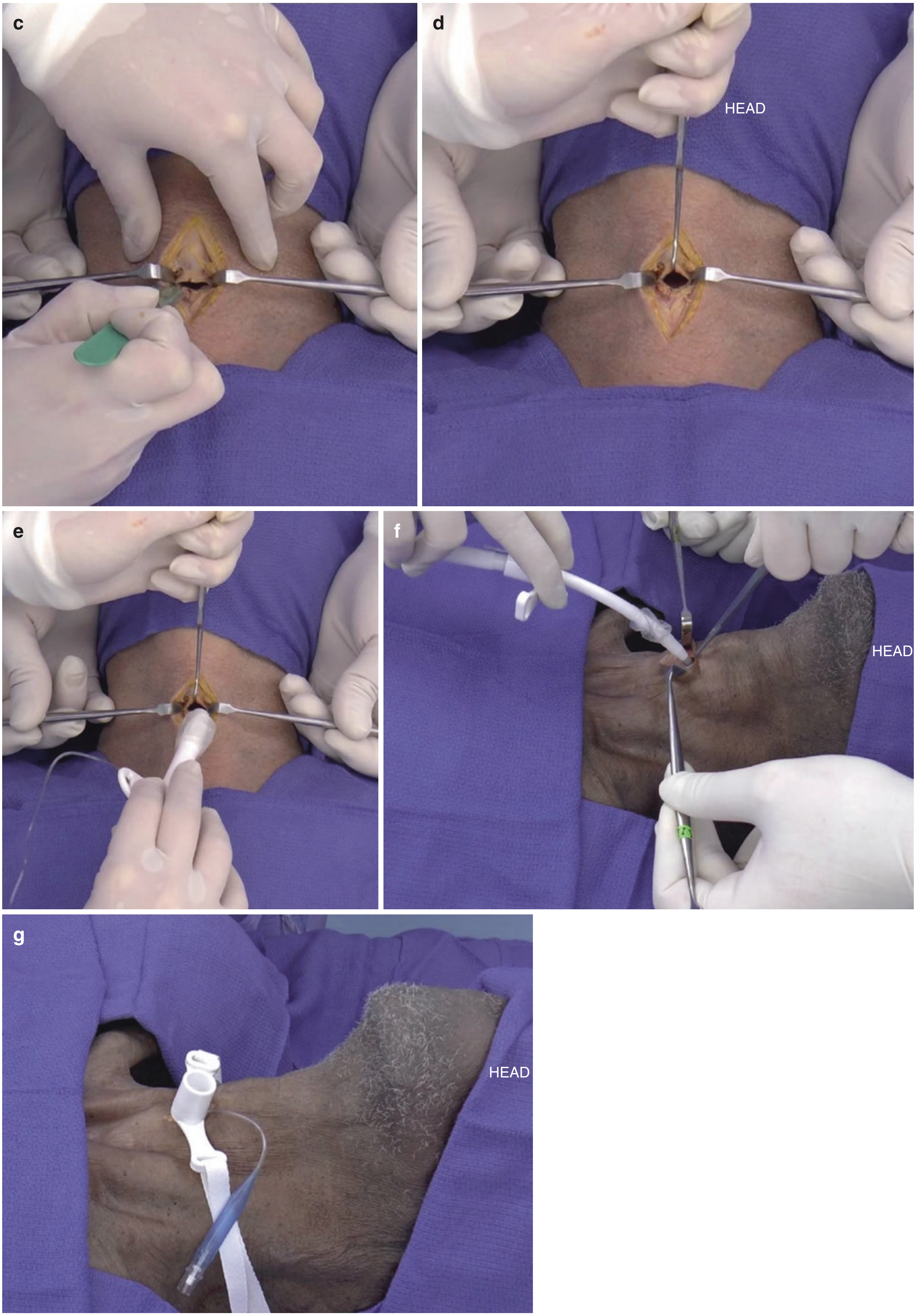


Fig. 4.6 (continued)

4.6 Technique: Percutaneous Cricothyroidotomy

- The percutaneous technique begins in the same manner as the open technique. Start by identifying the thyroid and cricoid cartilages, either using surface anatomy or the four-finger technique. Stabilizing the thyroid cartilage with the non-dominant hand as described above and retracting the skin with the same hand, use a scalpel to make a smaller (5–10 mm) skin incision in the vertical direction over the cricothyroid space.
- Note that the percutaneous technique is more easily performed with the physician standing on the patient's left if the physician is right-hand dominant.
- Insert the angiocatheter, connected to a syringe, into the airway through the cricothyroid membrane oriented toward the carina at a 45 ° angle to the skin (Fig. 4.7a).
- Negative pressure must be applied to the syringe while it is advanced through the soft tissues. If there is time, the syringe can be prefilled with normal saline in order to facilitate confirmation of entry into the airway with the appearance of air bubbles. Loss of resistance and aspiration of air through the syringe confirms the correct position of the needle in the airway.
- Advance the catheter overlying the needle in the airway with the non-dominant hand until it is hubbed at the skin, and remove the needle and syringe (Fig. 4.7b). Thread the wire into the airway through the catheter in the cricothyroid membrane (Fig. 4.7c, d).
- Once the wire is located in the airway, remove the catheter. Preload the dilator within the lumen of the cricothyroidotomy tube (Fig. 4.7e), and pass these together over the wire and into the airway (Fig. 4.7f). When doing so, ensure the dilator is not displaced from within the cricothryoidotomy tube and that the guidewire is not inadvertently advanced further or withdrawn from the airway.
- Remove the dilator and the guidewire together once the cricothyroidotomy tube is in place.
- Confirm proper placement of the tube in the airway as described above for the open technique, and secure it to the skin. Clear the airway of blood and secretions by suctioning through the cricothyroidotomy tube.

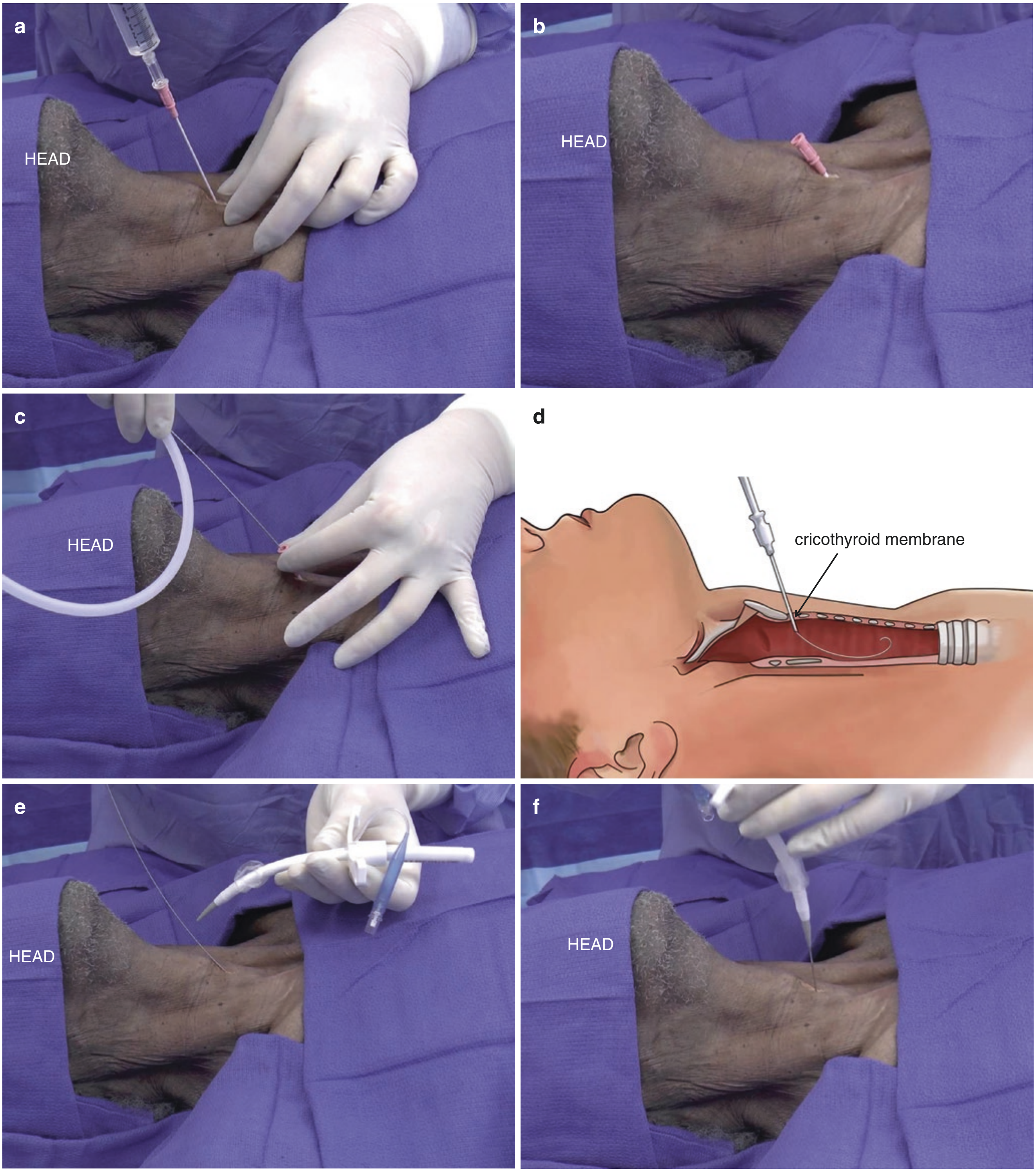


Fig. 4.7 (**a**–**f**) Steps of the percutaneous cricothyroidotomy technique. Stabilize the larynx and create a 5–10 mm vertical incision in the skin and subcutaneous tissue overlying the cricothyroid membrane. Insert the angiocatheter connected to a 10 cc syringe through this incision and into the airway through the cricothyroid membrane at a 45° angle, aiming towards the carina (**a**). After entry into the airway is confirmed by aspiration of air, advance the catheter to the level of the skin and remove the needle and syringe (**b**). Thread the wire into the airway through the catheter in the cricothyroid membrane (**c**, **d**) and remove the catheter. Place the dilator into the lumen of the cricothyroidotomy tube (**e**) and advance these together over the wire and into the airway (**f**). Secure the tube in place

4.7 Tips and Pitfalls

- A cricothyroidotomy may be a difficult procedure in patients with a short and thick neck or in the presence of a large neck hematoma.
- The selection of the open versus percutaneous technique should be made according to the physician's preference and the availability of a percutaneous kit.
- With a right-hand-dominant physician, percutaneous cricothyroidotomy is best done from the patient's left side.
- In very young pediatric patients, transtracheal needle jet ventilation (Chapter 5) is preferred over cricothyroidotomy.
- Use the four-finger technique to identify the cricothyroid space if the surface anatomy is obscured.
- Do not be afraid of making a large skin incision. A skin incision made too conservatively may inhibit the passage of the tube into the airway.
- A vertical skin incision reduces the risk of iatrogenic injury and bleeding from the anterior jugular veins and has the advantage of being extensile.
- The thyrohyoid space may be mistaken for the cricothyroid space, and the tube may be inserted too high.
- If the skin incision is made below the cricothyroid space, the thyroid isthmus may be encountered, and bleeding can ensue. If the skin incision is made too high and the thyrohyoid space is entered instead of the cricothyroid space, damage to the vocal cords can occur.
- To avoid passage of the tube into the subcutaneous tissues instead of the airway, utilize the tracheal hook with the open technique to immobilize the larynx and directly visualize the passage of the tube into the airway. With the percutaneous technique, aspiration of air or evacuation of prefilled normal saline as the needle is advanced suggests entry into the airway.
- Posterior tracheal perforation is a serious complication. Do not plunge the scalpel deeply through the cricothyroid membrane in the open technique. Halt the advancement of the needle in the percutaneous technique once air is aspirated. Do not insert the needle, any instruments, or the tube in a vertical direction. Instead, insert at a downward angle directed toward the carina, following the route of the trachea.
- Cricothyroidotomy can be utilized in adults for prolonged airway access with a low incidence of subglottic stenosis. The concept of routine conversion of a cricothyroidotomy into a formal tracheostomy is outdated and unnecessary.

5 Transtracheal Needle Ventilation

Morgan Schellenberg and Aaron Strumwasser

5.1 Surgical Anatomy

- For detailed descriptions of the anatomy of the adult larynx and trachea, please refer to surgical anatomy in ***Chapter 3: Open Tracheostomy*** and ***Chapter 4: Cricothyroidotomy***.
- There are anatomical differences between the adult and pediatric airway that merit emphasis. In children less than 10–12 years of age the airway is small and the cartilaginous prominences can be subtle on palpation. Some anatomical features in children, such as larger tongue/mouth ratio, smaller pharynx, larger floppy epiglottis, anterior vocal cords/larynx, narrower cricoid cartilage, and softer tracheal rings, make endotracheal intubation more difficult than in adults.
  - In older children and adolescents, the laryngeal prominence at the upper border of the thyroid cartilage is easily felt, with the cricothyroid membrane palpated immediately inferior to the thyroid cartilage.
  - In infants and younger children, the laryngeal prominence is not developed, and the thyroid cartilage is not easily identified. A better method to identify the cricothyroid membrane is to begin at the tracheal rings and palpate superiorly to locate the prominence of the cricoid cartilage. The cricothyroid membrane resides superiorly.
  - If the cricothyroid membrane cannot be identified, percutaneous transtracheal needle ventilation (TTNV) can be safely performed by inserting the needle between the tracheal rings.

5.2 General Principles

- An emergency surgical airway is required when a patient with an upper airway pathology cannot be ventilated or oxygenated ("can't intubate, can't ventilate") using basic and/or advanced noninvasive airway interventions, such as bag-valve-mask ventilation, endotracheal intubation, or laryngeal mask.
- In adults and older children (age 12 or greater), the emergency surgical airway of choice is cricothyroidotomy (***Chapter 4: Cricothyroidotomy***). Cricothyroidotomy is relatively contraindicated in children under 12 years of age because of the risk of damage to the larynx and surrounding structures and the long-term risk of stenosis because of the small diameter of the pediatric trachea. For these reasons, TTNV is the procedure of choice for emergency ventilation and oxygenation in the pediatric patient when non-surgical means of airway support have failed.
- To obtain access to the airway, the first step of TTNV involves the insertion of a catheter over a needle into the trachea between tracheal rings. The catheter can be used for mechanical ventilation using various techniques, such as connection to wall oxygen, a bag-valve mask, or jet ventilation.
- TTNV may be used in all ages, but its main indication is in infants and children up to 10–12 years of age.
- TTNV should be replaced with a formal endotracheal tube or tracheostomy as soon as possible, usually within a few hours. This is particularly important in patients with increased intracranial pressure as TTNV is often associated with CO_2 retention.

M. Schellenberg · A. Strumwasser (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: Aaron.strumwasser@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_5

- The tidal volume delivered through TTNV is determined by the size of the catheter, the inspiratory pressure, the duration of inspiration, and lung compliance. Up to one-third of oxygen delivered by the catheter escapes through the glottis and then through the mouth and nose.
- TTNV delivers ventilation and oxygen using high-frequency, low tidal volumes.

5.2.1 Indications

- TTNV should be considered in pediatric patients with severe airway problems, when usual airway procedures such as bag-valve-mask ventilation, endotracheal intubation, or laryngeal mask, fail to secure the airway and ventilation.
- Pathologies which may cause airway obstruction requiring TTNV include severe oromaxillofacial trauma and severe swelling of the airway (due to infection, allergic reaction, burns, or post-extubation edema).

5.2.2 Contraindications

- Absolute contraindications to TTNV include severe laryngotracheal injuries and the ability to secure the airway with conventional noninvasive techniques.
- Relative contraindications include large anterior neck swelling or hematoma, extensive anterior neck subcutaneous emphysema, and coagulopathy.

5.3 Patient Preparation and Positioning

- The patient should be placed supine. In non-trauma situations and if the cervical spine has been cleared after trauma, it is helpful to extend the patient's neck (Fig. 5.1). If the cervical spine has not been cleared, the neck should be left in a neutral position.
- Although the surface anatomy in children can be obscured due to the small size of the underlying structures, an attempt should be made to identify the thyroid and cricoid cartilages and trachea by palpation as described above. The four-finger technique used as a landmark for the cricothyroid membrane in adults will not work in children due to their small size (Fig. 5.2).
  – If the cricothyroid membrane cannot be located, TTNV can be safely performed by introducing the needle between the tracheal rings.

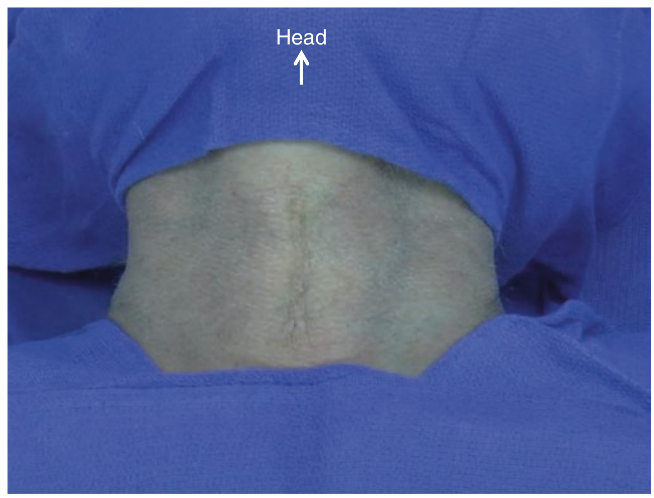


Fig. 5.1 Optimal position prior to needle cricothyroidotomy. Head extension allows for palpation of bony prominences of the neck and minimizes the distance from the cricothyroid membrane to the skin. If there is a concern about cervical spine injury, the neck should be held in a neutral position

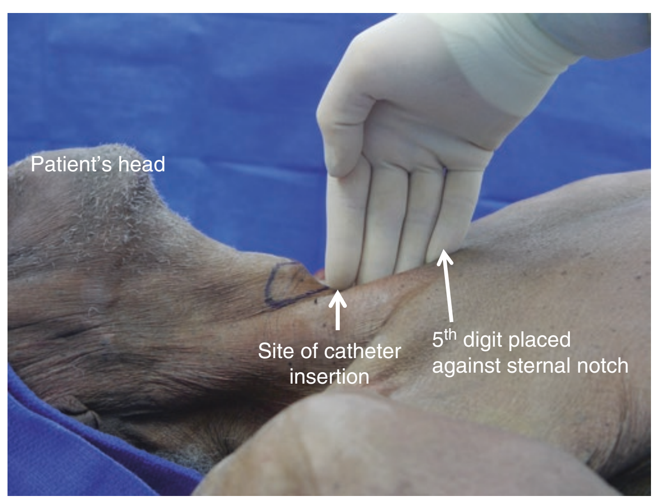


Fig. 5.2 The four finger technique is used as a landmark for identifying the cricothyroid membrane in adults. The cricothyroid space is under the tip of the index finger. While this technique works well for adults, it may not be similarly applicable in young children

5.4 Special Instruments

- Needle cricothyroidotomy and TTNV can be performed using standard supplies readily available in any ICU or emergency room. There are also commercial available kits. It is recommended that emergency airway carts include all needed supplies for TTNV.
- Basic equipment for TTNV include 12–18G angiocatheter(s), 10 mL syringe filled with normal saline, oxygen source, and oxygen tubing.
- If a bag-valve-mask will be used for patient ventilation, a connector with adaptor is needed. Often, an infant endotracheal tube connector may be used for connection to the bag-valve-mask.
- Complete kits include the following:
  - Angiocatheters: for infants and young children, 16–18G. For adolescents and adults, 12–16G
  - Oxygen source with regulator (wall outlet, oxygen tank, flush valve from mechanical ventilator)
    For infants and young children, maximum flow rate of 10–12 L/min
    For adolescents and adults, maximum flow rate of 15 L/min
  - High-pressure oxygen tubing with manual in-line valve
    Scissors are needed to cut a side port in the oxygen tubing close to the patient end to allow for intermittent ventilation (Fig. 5.3a, b).
    Commercially available systems are also available (Fig. 5.4).
  - Oxygen connector
    Direct connection to oxygen tubing
    Y-connector to oxygen tubing
    Three-way stopcock to oxygen tubing

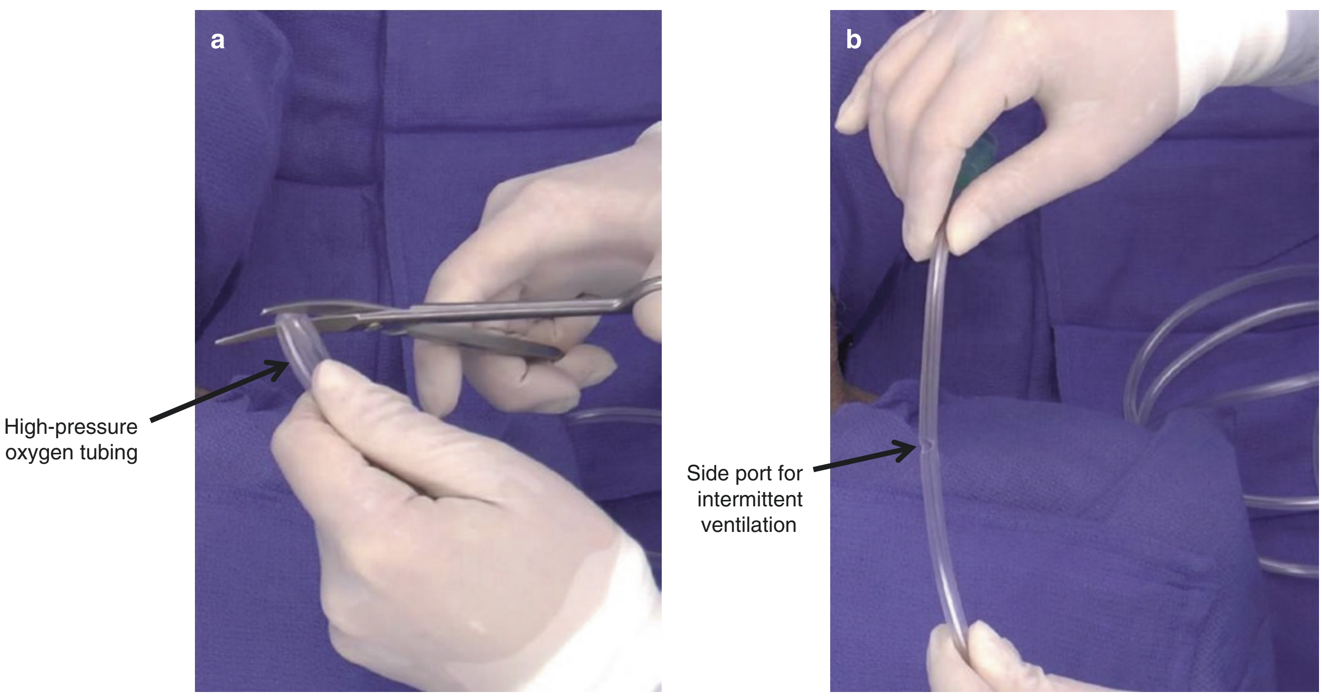


Fig. 5.3 (**a**, **b**) High Pressure Oxygen Tubing with Manual In-line Valve. A side port is created in the oxygen tubing with scissors, close to the patient end to allow for intermittent ventilation (**a**). This side port can be intermittently occluded to allow for oxygen delivery and ventilation (**b**)

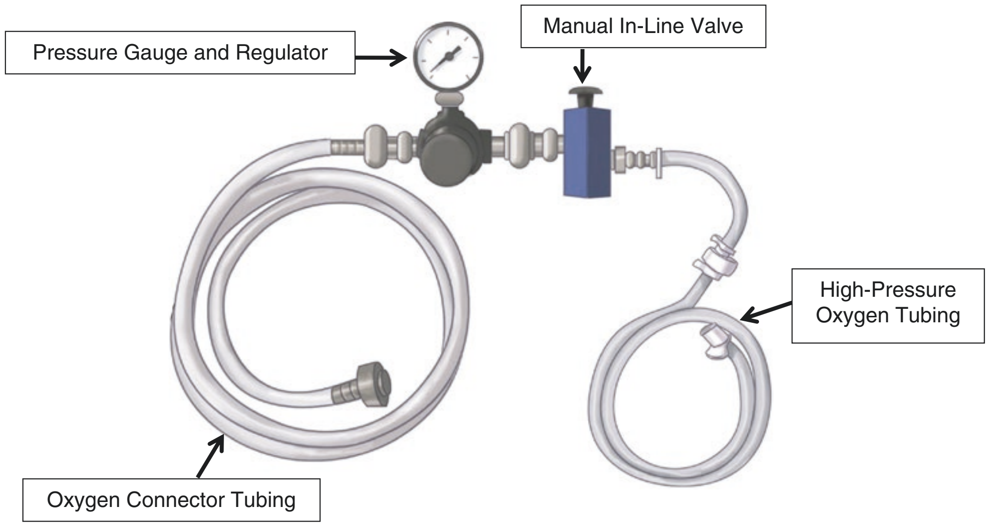


Fig. 5.4 Commercially-available setup for percutaneous trans-tracheal needle jet ventilation (cricothyroidotomy needle and oxygen source not shown)

5.5 Surgical Technique

- Universal precautions, sterile preparation, and proper surgical draping should be used if time allows.
- Begin by performing needle cricothyroidotomy. Stabilize the thyroid cartilage with the non-dominant hand, and identify the cricothyroid space with the index finger of the dominant hand.
- With the dominant hand, hold a 10 mL syringe filled with normal saline, attached to an appropriately sized angiocatheter. Insert the angiocatheter between tracheal rings or through the cricothyroid space, at an angle of 30–45°, toward the feet (Fig. 5.5a, b). A small incision on the skin with scalpel (11 blade) may facilitate the insertion of the angiocatheter.
- The catheter is advanced while applying negative pressure on the syringe, until air bubbles are aspirated, confirming entry into the trachea. The catheter should then be advanced, while the needle is gradually withdrawn, until the catheter hub is flush with the skin. The needle and syringe are then withdrawn entirely from the patient, leaving just the catheter in situ (Fig. 5.5c). The catheter is secured in place with a suture.
- After placement of the catheter, ventilation can be performed with a standard bag-valve-mask or jet ventilation. If a bag-valve-mask system is used, an appropriate adaptor for connection to the catheter is needed.
- The first step in jet ventilation is to connect the oxygen tubing to the catheter (Fig. 5.6a, b). The amount and rate of the delivered oxygen are based on age. Confirm placement by delivering a few short bursts of gas to ensure the equipment is functioning properly and that no resistance is encountered. Begin regular ventilation with inspiratory/expiratory (I:E) ratio 1:4 and respiratory rate 10–12 breaths/min in the patient without complete upper airway obstruction; adjust in patients with complete airway obstruction—I:E ratio 1:8–1:10 with respiratory rate of 5–6 breaths/min. Occlude the side port with a finger to deliver the inspiratory phase of the breath cycle (Fig. 5.6c, d). Alternatively, a Y-connector can be used instead of a side port (Fig. 5.6e). To allow for the expiratory phase, remove the finger from the side port (Fig. 5.6f) or Y-connector (Fig. 5.6g).
- Once the catheter is in place and TTNV is established, the airway should be closely observed for any kinking or dislodgement of the catheter, for the development of subcutaneous emphysema (which may indicate dislodgment of the catheter), or for the development of significant bleeding. Chest radiograph should be obtained as soon as possible. Adequacy of TTNV should be assessed using clinical parameters as well as frequent blood gas analysis.

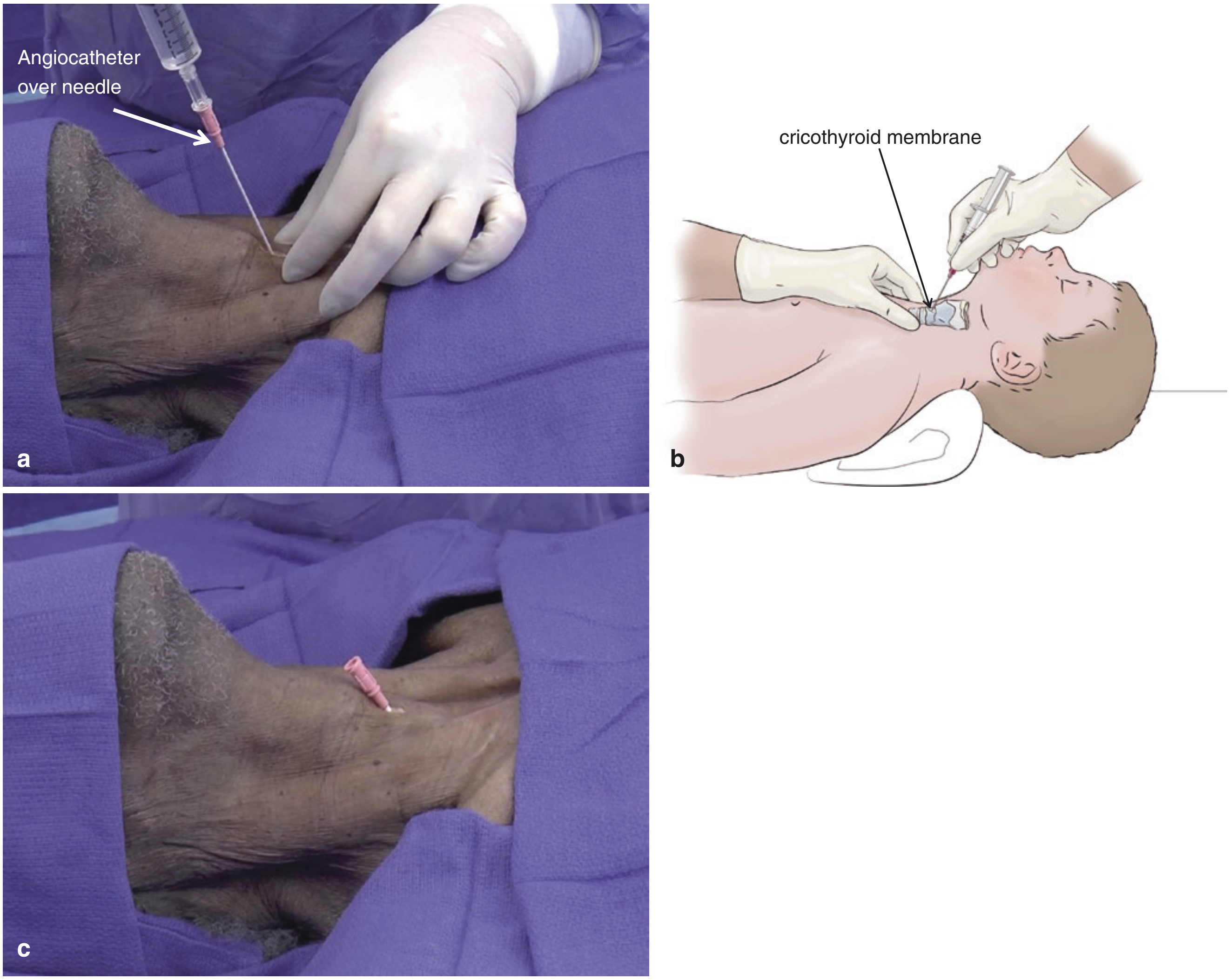


Fig. 5.5 (**a**–**c**) Steps of the needle cricothyroidotomy technique. A small skin incision is made over the cricothyroid membrane. The angiocatheter is inserted through the cricothyroid membrane and directed towards the carina. Entry into the airway is confirmed with the aspiration of air bubbles (**a**, **b**). The catheter is advanced over the needle and into the airway, until the hub of the catheter is flush with the skin. The needle and syringe are withdrawn, leaving just the catheter in situ (**c**)

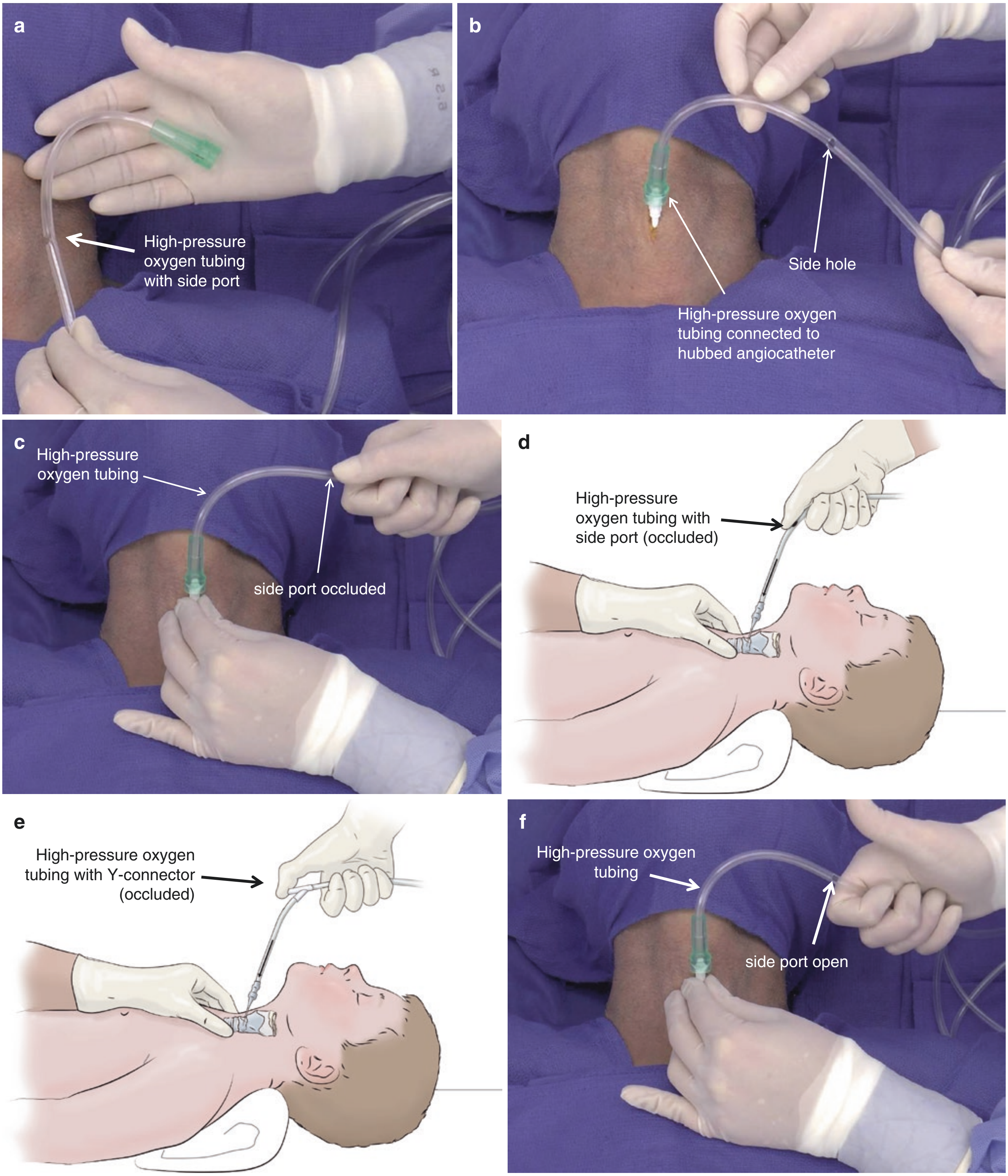


Fig. 5.6 (**a**–**g**) Technique of trans-tracheal needle ventilation: Connect the oxygen tubing to the catheter (**a**, **b**). Occlude the side port (**c**, **d**) or Y-connector (**e**) with a finger to deliver the inspiratory phase of the breath cycle and then remove the finger to allow for the expiratory phase (**f**, **g**)

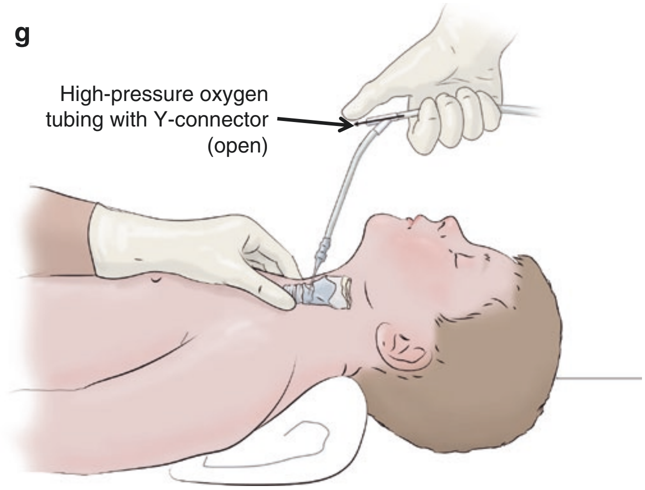


Fig. 5.6 (continued)

5.6 Tips and Pitfalls

- Once the catheter is placed into the airway, one of the physician's hands should be used to immobilize it at the level of the skin. This is critical to avoid dislodgment of the catheter.
  – If there is concern for dislodgement, disconnect the oxygen tubing, and reconnect the syringe filled with normal saline to the catheter. Attempt to aspirate air. If this is not possible, the catheter has dislodged out of the airway. Reintroduce the needle and syringe through the catheter, and attempt to reenter the airway either by advancing or withdrawing the catheter until air can be aspirated again.
- Oxygen sources can be a wall outlet, oxygen tank, or mechanical ventilator fashioned with the appropriate connections. The common gas outlet of the anesthesia machine should not be used as most machines have a pressure-limiting valve.
- In situations where complete airway obstruction exists, the clinician should use longer expiratory time and lower oxygen delivery pressure. Diminished chest fall with expiration should lead to further reduction in respiratory rate (5–6 breaths/min), prolongation of expiratory time (I:E 1:8–10), and chest radiography to investigate for barotrauma.
- A small amount of subcutaneous emphysema is normal and typically resolves without intervention. However, large amounts of subcutaneous emphysema or decreasing oxygen saturation as measured by pulse oximetry should alert the physician to the potential that the catheter has become dislodged from the airway or the catheter is kinked.
- TTNV is not a definitive airway. It merely buys time to either achieve endotracheal intubation safely or to perform a tracheostomy.

6 Bronchoscopy in the Intensive Care Unit

Shihab Sugeir and Alice Gallo de Moraes

6.1 Indications

- Diagnostic
  – Verification of endotracheal (ET) tube position.
  – Collection of bronchial secretions for cultures.
  – Identification of hemoptysis source.
  – Thoracic trauma.
  – Evaluation of inhalation injuries.
- Therapeutic
  – Awake intubation.
  – Clearance of retained secretions.
  – Foreign body/mucus plug removal.
  – Guidance to bedside percutaneous tracheostomy placement.
  – Balloon placement/selective airway intubation in cases of massive hemoptysis.

6.2 Equipment

- Fiber-optic scope.
- Fiber-optic scope tower with screen.
  – An external screen is not essential but helps with education and comfort of the bronchoscopist.
- Each scope and tower should be cleaned after individual patient use.

6.3 General Principles

- Should be performed by a trained intensivist.
- The lead assistant should be an ICU nurse or a respiratory therapist with knowledge of the equipment.
- Ideally, patients should have an ET tube with an inner diameter of 7.0 mm or higher.

6.4 Positioning

- Patients can be seated or in the supine position.

S. Sugeir (✉)
Keck School of Medicine, Department of Anesthesiology,
University of Southern California,
Los Angeles, CA, USA

Department of Anesthesiology, LAC-USC Medical Center,
Los Angeles, CA, USA
e-mail: Shihab.sugeir@med.usc.edu

A. G. de Moraes
Division of Pulmonary and Critical Care Medicine, Mayo Clinic,
Rochester, MN, USA

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_6

6.5 Technique

- General ICU bronchoscopy:
  - Usually done from the head of the bed, through ET tube if one is in place or with ET tube over the scope if being performed as part of fiber-optic intubation.
  - Flexible bronchoscope should be held with the left hand.
  - Patients should be properly sedated
  - Tracheobronchial tree should be anesthetized with topical anesthetic. Preferred analgesic is lidocaine 1 cc topically followed by 3 cc of air to clear the flexible bronchoscope circuit
  - Systematic evaluation of each pulmonary segment should be performed.

    Evaluation of the trachea and main carina (Fig. 6.1a, b)

    Evaluation of the right mainstem bronchus (Fig. 6.2a, b)

    Evaluation of the right upper lobe apical, anterior, and posterior segments (Fig. 6.3a, b)

    Evaluation of bronchus intermedius (Fig. 6.4a, b)

    Evaluation of the right middle lobe, medial and lateral segments (Fig. 6.5a, b)

    Evaluation of the right lower lobe medial, superior, anterior, lateral, and posterior segments (Fig. 6.6a, b)

    Evaluation of the left mainstem bronchus (Fig. 6.7a, b)

    Evaluation of the left upper lobe apico-posterior and anterior segments (Fig. 6.8a, b)

    Evaluation of the lingual superior and inferior segments (Fig. 6.8a, b)

    Evaluation of the left lower lobe superior, anteromedial, lateral, and posterior segments (Fig. 6.9a, b)
- Bronchoalveolar lavage (BAL): This technique is used to isolate a particular segment of the lung. The bronchoscope is "wedged" into the airway of interest, and fluid is instilled in 20–30 cc aliquots. After each aliquot, the fluid is either manually suctioned out with a syringe or mechanically suctioned out into a trap via wall suction. The purpose of this technique is to identify specific infections in the lower airways.

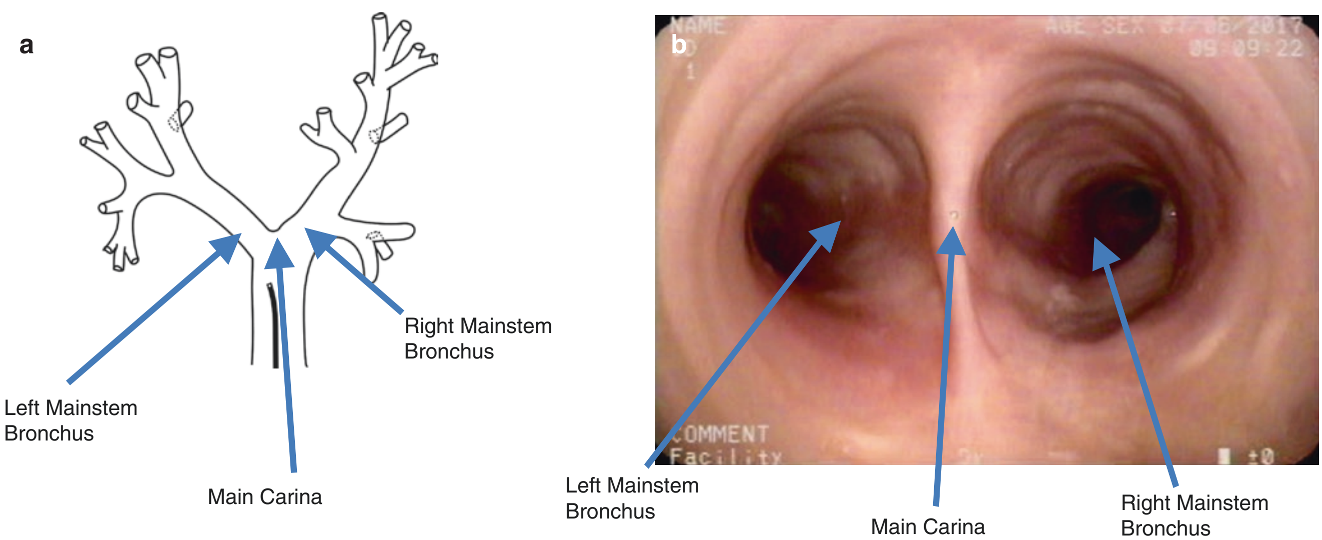


Fig. 6.1 (**a**, **b**) A view from the trachea showing the carina and right and left mainstem bronchi

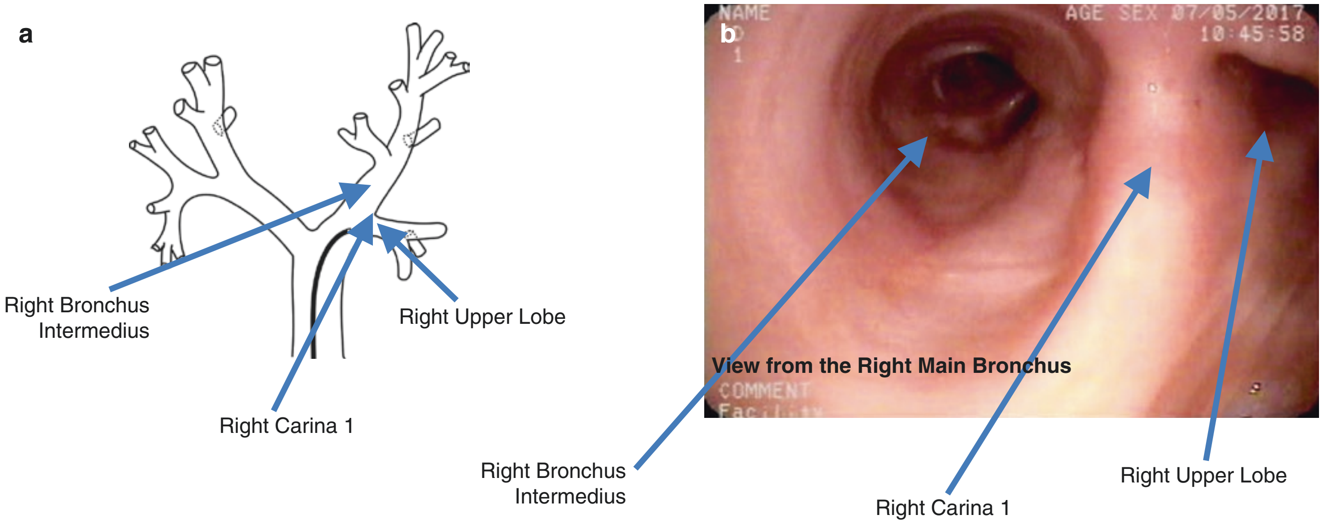


Fig. 6.2 (**a**, **b**) Traveling down the right mainstem bronchus you have the right upper lobe takeoff almost immediately and bronchus intermedius continuing down to the right middle and lower lobe. This division is demarcated by the first right carina

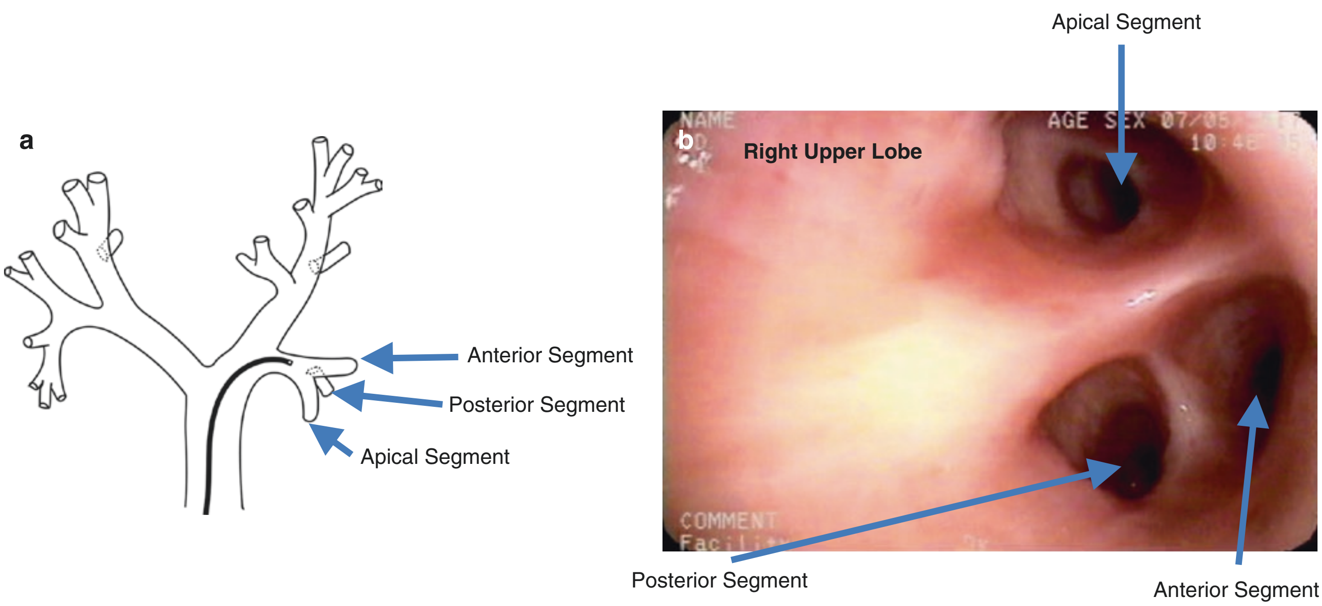


Fig. 6.3 (**a**, **b**) A view of the right upper lobe is shown with the anterior, apical, and superior segments

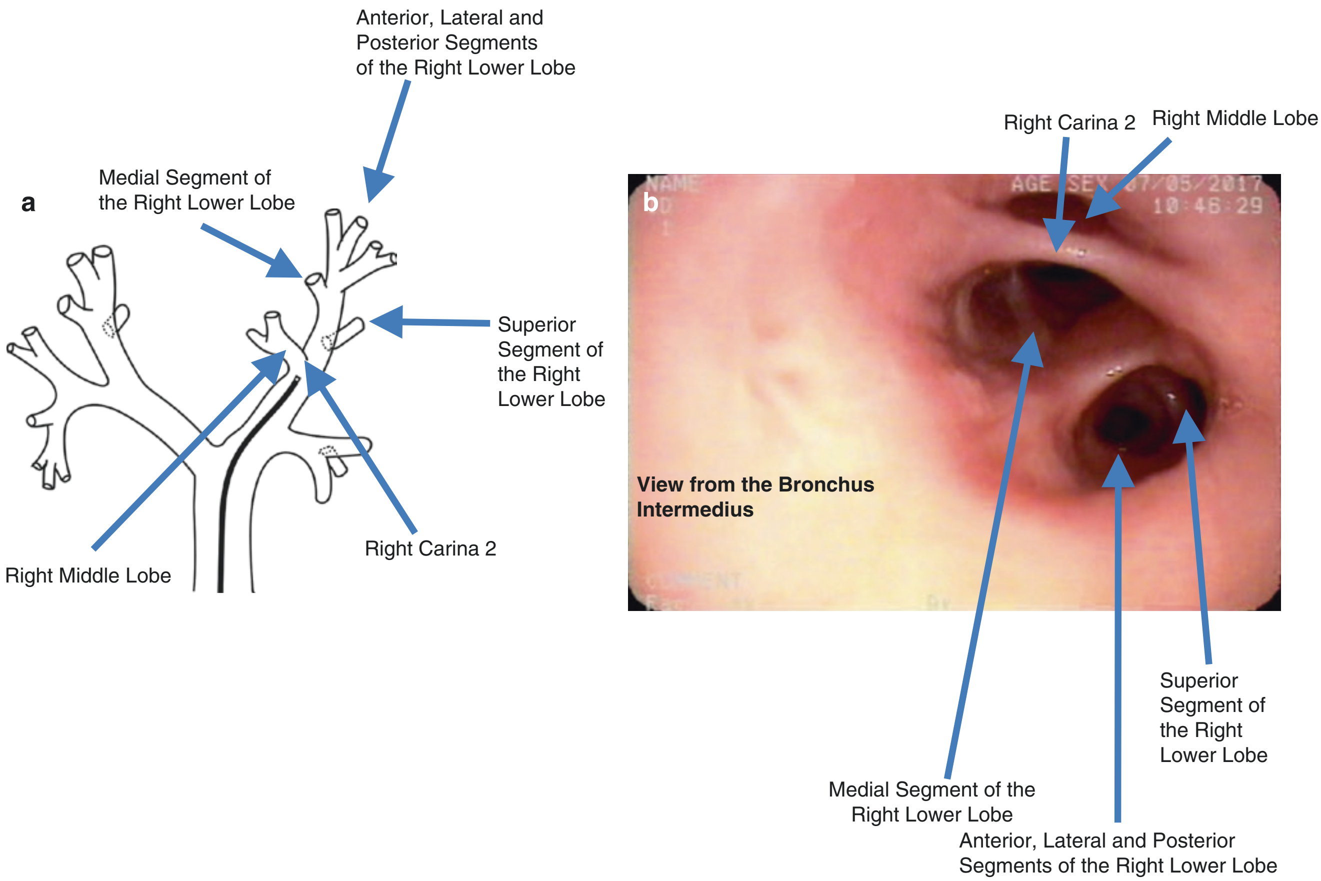


Fig. 6.4 (**a**) The second division when traveling down the bronchus intermedius is known as the second right carina and divides the right middle and lower lobes. (**b**) The Right middle Lobe arrow should point to the superior opening above Right Carina 2

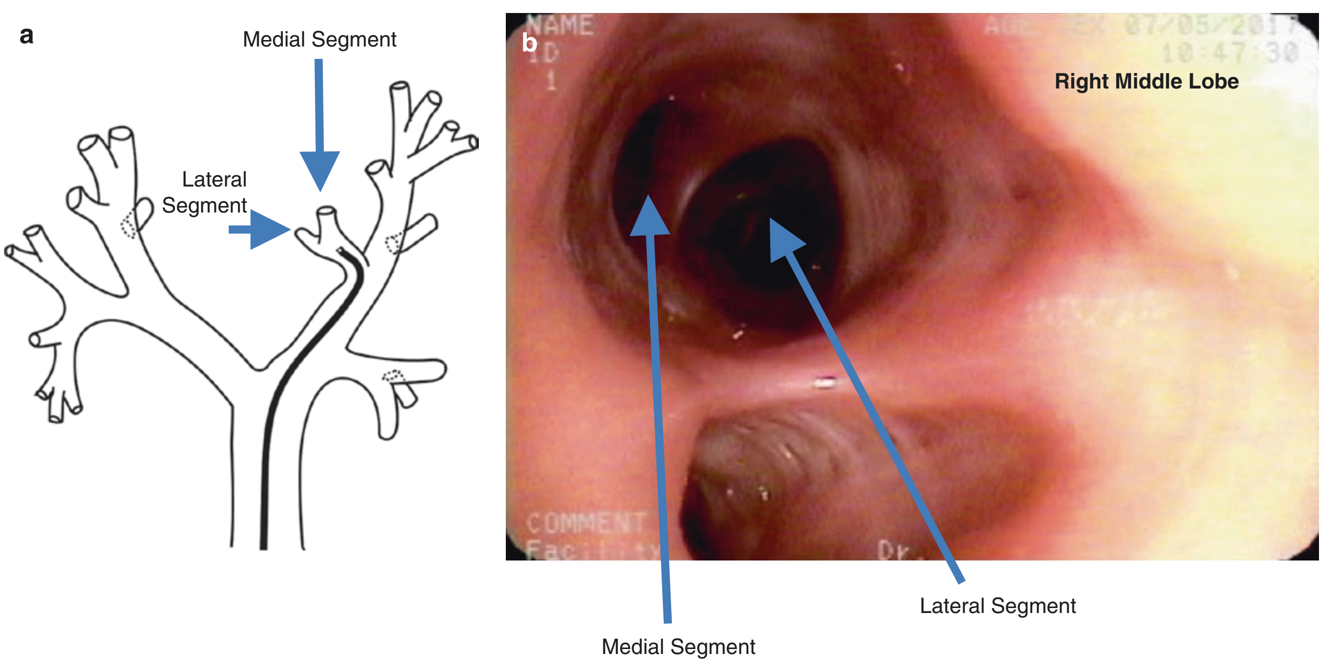


Fig. 6.5 (**a**, **b**) A view of the right middle lobe is shown with the medial and lateral segments

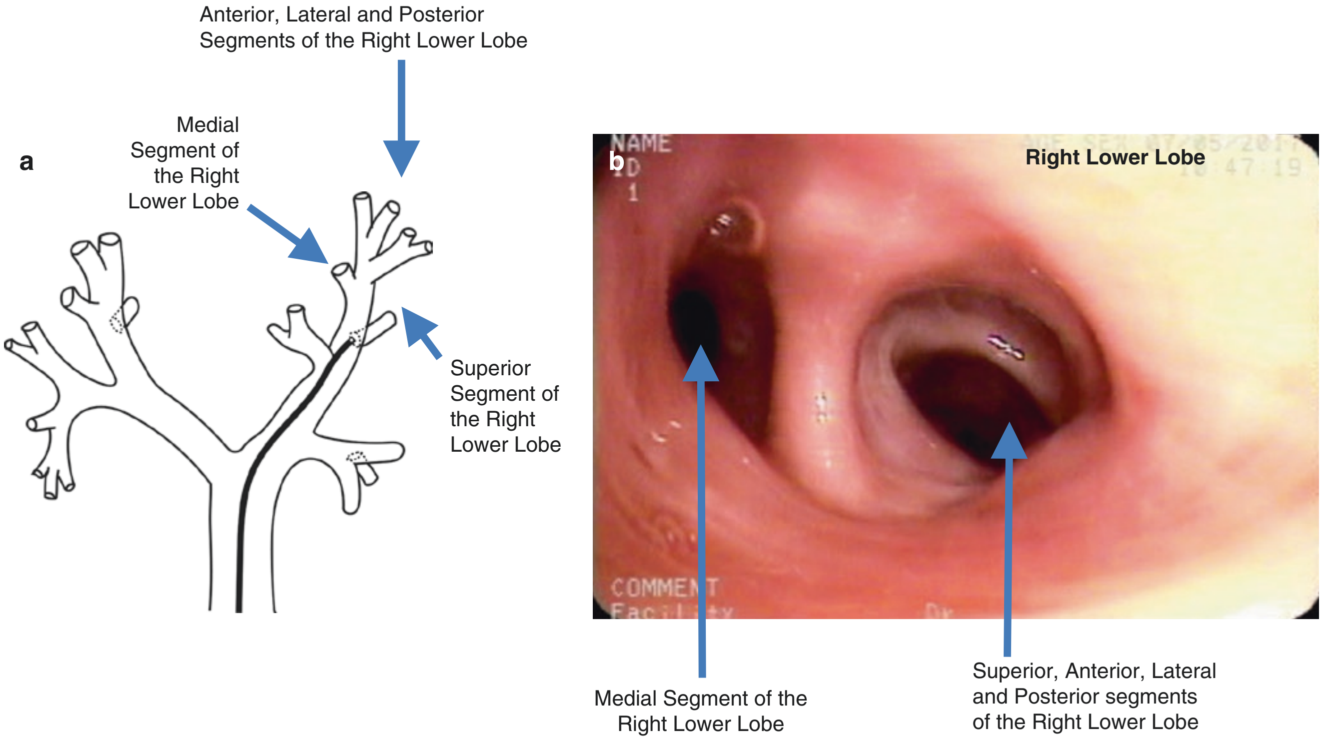


Fig. 6.6 (**a**, **b**) A view of the right lower lobe

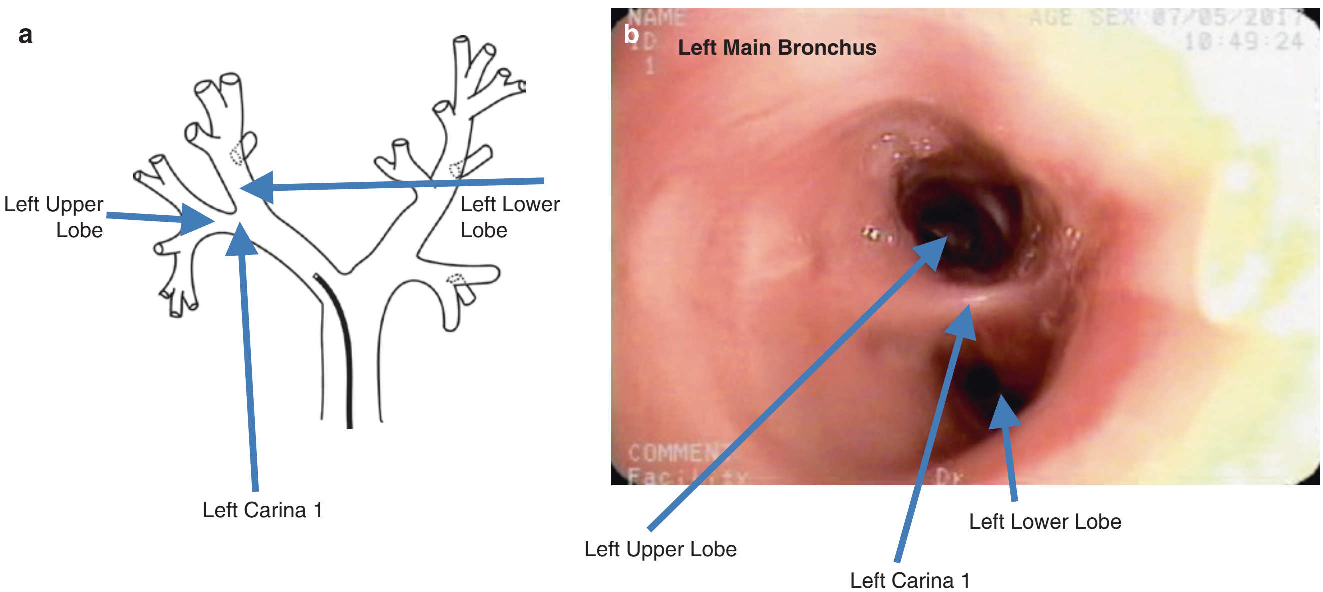


Fig. 6.7 (**a**, **b**) Shown is the view from the left mainstem bronchus. In this view a bronchoscopist should be able to see the left carina and the take off of the left upper lobe and left lower lobe

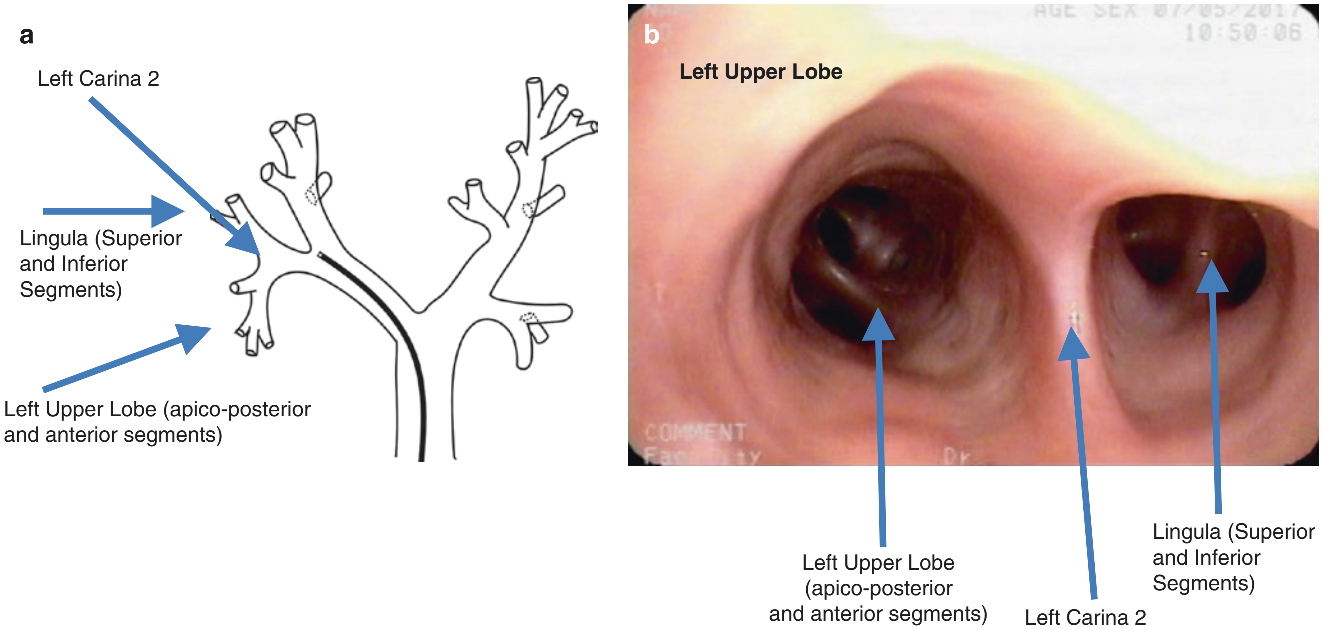


Fig. 6.8 (**a**, **b**) Traveling from the left mainstem bronchus towards the left upper lobe the first bifurcation is the division to the lingula and left upper lobe

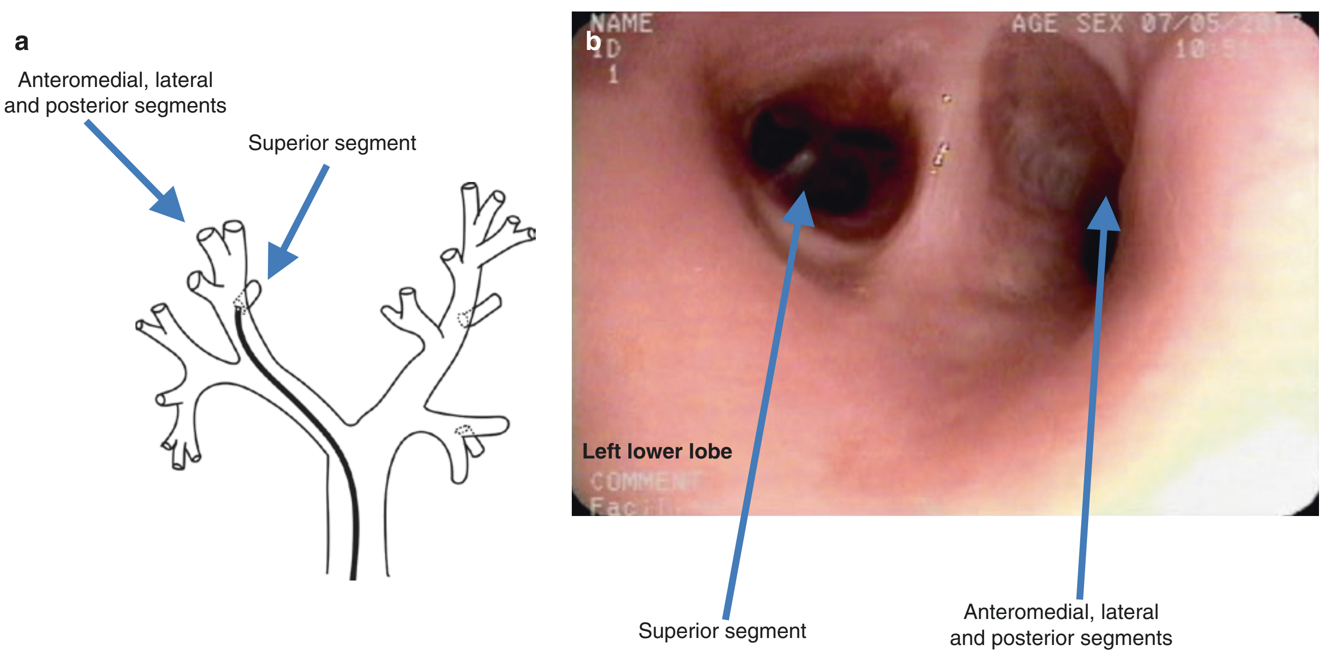


Fig. 6.9 (**a**, **b**) The left lower lobe is visualized here with superior segment and basal segments

6.6 Tips and Pitfalls

- Be aware of decrease in tidal volume (TV) and increase in peak pressures while performing a bronchoscopy in an intubated patient.
- PEEP and TV may be reduced or even disappear when suction is applied.
- Decrease in PEEP, TV, and oxygenation can be minimized by increasing FiO2 to 100% and by bag ventilating the patient during the procedure.
- If patient is to remain on mechanical ventilation, volume-control mode is the preferred mode. The transient increase in airway resistance during the procedure would cause the TV to decrease even further on a pressure-control mode. Pressure-support mode is contraindicated during flexible bronchoscopy in the ICU.
- A swivel adapter can also be used to minimize TV loss.
- Flexible bronchoscopy should be performed with caution in patients with elevated intracranial pressure (ICP).

7 Bronchoalveolar Lavage

Zachary Warriner and Meghan Lewis

7.1 General Principles

- Bronchoalveolar lavage (BAL) involves obtaining a specimen from the lower respiratory tract and therefore requires proficiency in bronchoscopy.
- Thoracic imaging modalities, such as chest radiography or CT scan, may be used to guide the location of specimen acquisition.
- Indications for BAL include:
  - Diagnosis of pulmonary infection
    - Bacterial, fungal, or viral isolation
    - Quantitative evaluation of the pathogen
    - Culture for speciation and sensitivity determination
  - Distinguishing ARDS from cardiogenic pulmonary edema
    - Evaluation of the protein and neutrophil content
- BAL cultures should be sent for both gram stain and quantitative culture analysis. Gram stain can be utilized to tailor early antibiotic therapy. The specimen is diagnostic of pneumonia if the quantitative culture demonstrates at least 10^4 CFU/mL.
- The accuracy of BAL is optimized if it is performed prior to the initiation of antibiotics.

7.2 Instruments (Fig. 7.1)

- Fiber-optic bronchoscope.
- Sterile collection trap(s).
- Sterile saline.
- Suction tubing and vacuum source.

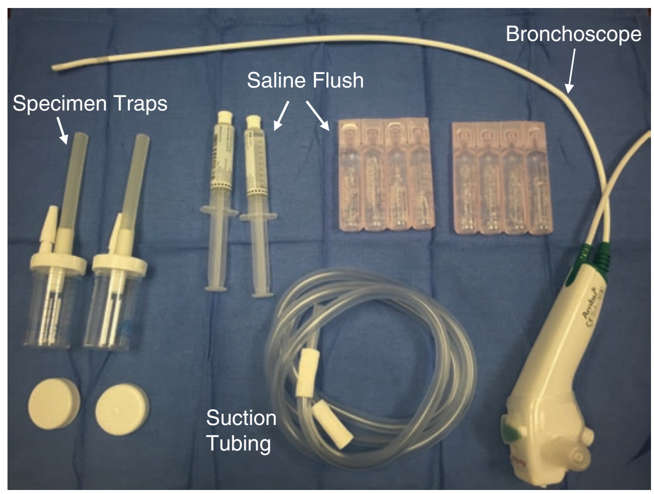


Fig. 7.1 BAL equipment

Z. Warriner · M. Lewis (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: Zachary.warriner@med.usc.edu; meghan.lewis@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_7

7.3 Positioning

- Refer to Chapter 6: Bronchoscopy in the ICU.

7.4 Technique

- Refer to Chapter 6: Bronchoscopy in the ICU.
- After evaluation of the tracheobronchial tree, a BAL specimen should be obtained in any segment with purulent secretions or in the segment(s) corresponding to the location of infiltrate appreciable on thoracic imaging.
- If any prior suctioning of the airway or endotracheal tube secretions has been performed, the bronchoscope should be irrigated with sterile saline prior to obtaining the BAL specimen to prevent contamination.
- The bronchoscope should be connected to the sterile collection trap, which is connected to suction. A sterile saline syringe should also be attached to the top of the bronchoscope (Fig. 7.2).
- The bronchoscope should be advanced distally into the desired tracheobronchial tree until gentle resistance is appreciable, appropriately wedging the bronchoscope in the area of concern.
- Sterile isotonic saline is then instilled for appropriate lavage.
  - Assure the saline irrigation is visible on bronchoscopic view during instillation.
  - Avoid suction until instillation of irrigation is complete, to assure adequate volume of sample is collected.
- Suction should then be applied to evacuate the irrigated segment into a sterile collection device, assuring the trap remains in a dependent position to prevent evacuation and loss of obtained specimen.
  - Alternatively, if suction is unavailable, the specimen may be aspirated with a sterile syringe through the irrigation channel.
- Instillation and evacuation of fluid in 20 mL aliquots should be repeated until the segment is fully cleared, as this assures sampling of the distal alveoli, not only the distal bronchus.
- The collection device is then removed and labeled with appropriate identification information.
- If additional specimens are required, the bronchoscopy suction channel should be appropriately flushed to avoid contamination of subsequent cultures.
- At the conclusion of the procedure, the operator should ensure the entirety of visible saline irrigation has been evacuated completely.

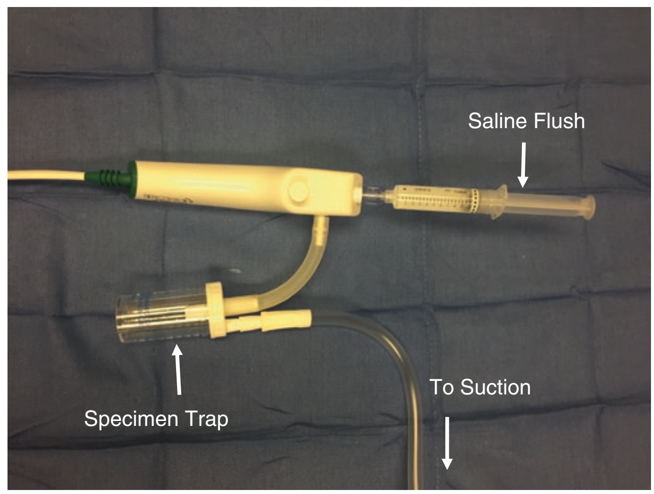


Fig. 7.2 Final setup for obtaining BAL specimen

7.5 Tips and Pitfalls

- Pulsations of suction, rather than continuous application, can be helpful to avoid collapse of the distal airways. This prevents de-recruitment of alveoli and hypoxemia.
- Suctioning during obstructed bronchoscopic view should be avoided to prevent mucosal injury.
- It is preferable to avoid suctioning endotracheal tube secretions or upper airway secretions prior to obtaining a BAL specimen to avoid the potential for contamination.

Part II

Respiratory

8 Thoracostomy Tube Insertion

Jennifer Cone and Demetrios Demetriades

8.1 General Principles

- A thoracostomy tube is indicated in patients with a pneumothorax, hemothorax, or pleural effusion.
- Small, asymptomatic pneumothoraces or hemothoraces do not need drainage. However, liberal thoracostomy tube placement should be considered in small pneumothoraces in patients on mechanical ventilation or for planned air transportation, because of the risk of tension pneumothorax.
- Strict aseptic techniques (mask, sterile gloves, gown, and, drapes) should be followed throughout a thoracostomy tube insertion to reduce the risk of empyema. A single dose of cefazolin should be given prior to the tube insertion. There is no need for longer antibiotic prophylaxis.
- Thoracostomy tubes may be inserted either via an open technique or a percutaneous insertion.
- Small-size tubes (28–32 in adults, refer to Broselow tape for children) are as effective as larger tubes in draining hemothoraces.
- The chest tube should be removed as soon as possible to reduce the risk of empyema.

J. Cone · D. Demetriades (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_8

8.2 Patient Positioning

- The patient should be positioned supine with the arm abducted at >90°.

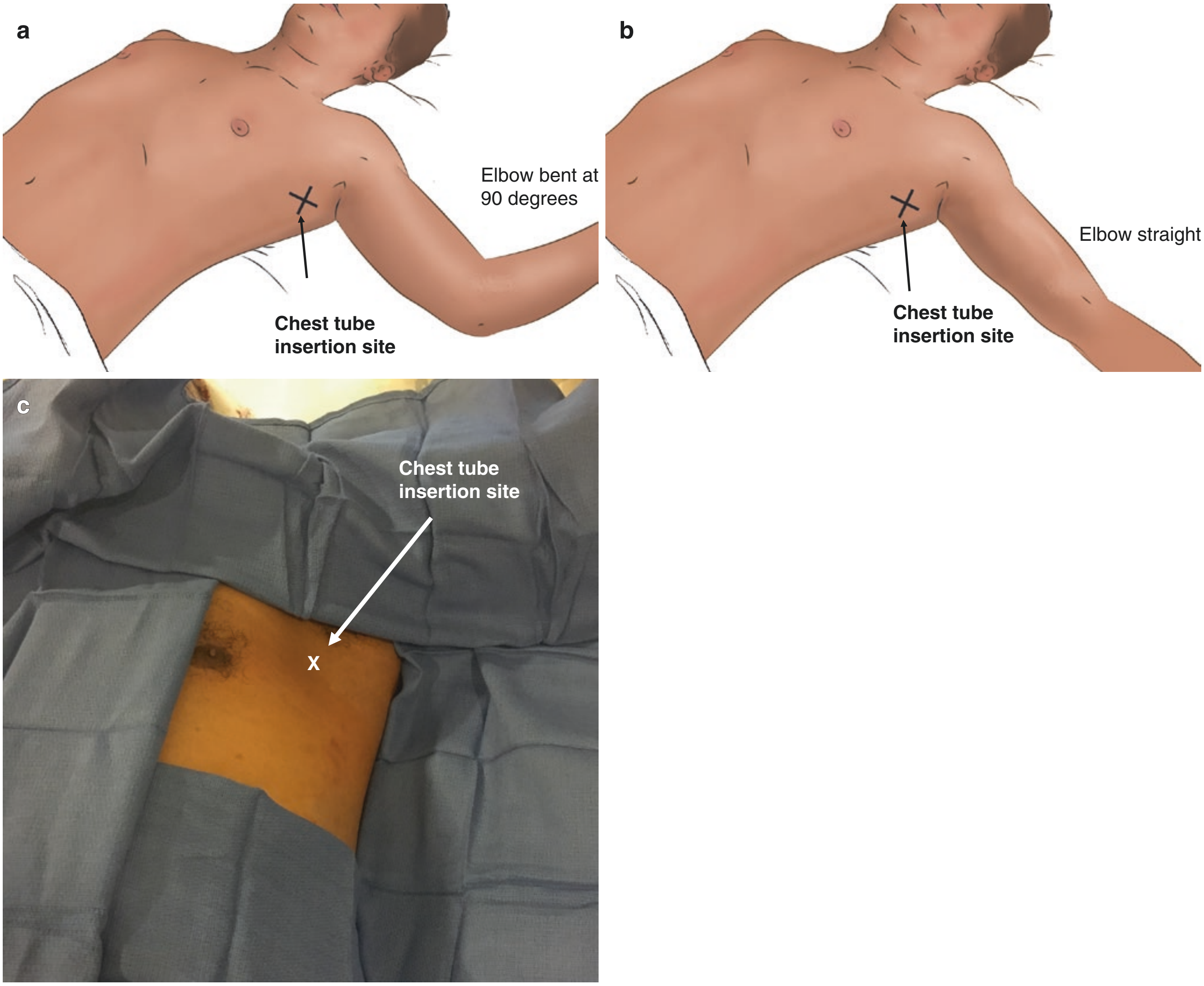


Fig. 8.1 The patient is positioned with arm abducted at 90° and elbow bent at 90° (**a**), or elbow in line with arm (**b**, **c**). The insertion site is the mid-axillary line, in the fourth or fifth intercostal space, at the level of the nipple in males or the infra-mammary crease in females

8.3 Site of Insertion

- Thoracostomy tubes are generally inserted in fourth or fifth intercostal space, in the mid-axillary line for both hemothorax and pneumothorax. This site corresponds to a point slightly above the nipple level in males or the inframammary fold in women. Insertion at a lower site risks injury to the diaphragm, which rises up to the sixth intercostal space during expiration. Intra-abdominal organs such as the liver or spleen may be injured. Insertion at a higher intercostal space risks injury to the axillosubclavian vessels and is uncomfortable for the patient when the arm is in the usual neutral position.

8.4 Open Technique

- A size 28–32 French tube is recommended for adults. The size of the tube in children should be determined on the basis of the age. There is no benefit to using a larger tube size. A straight tube is used in most cases. Curved tubes are more difficult to position correctly and are rarely used.
- The physician should be dressed in a surgical cap and mask with a sterile gown and sterile gloves.
- The skin is prepped with chlorhexidine prep sticks. In an emergency, a splash of betadine on the chest wall can be used. The chosen insertion site should be squared off with sterile towels and a standard surgical drape should be used.
- Local anesthetic, such as lidocaine with 1% epinephrine, is injected with a 21-gauge needle to create a skin wheel at the planned thoracostomy tube insertion site. The anesthetic should also be injected into the intercostal muscle to provide adequate analgesia.
- A 1.5–2 cm incision is made parallel to the ribs in the chosen insertion site. The incision is extended through the subcutaneous tissue down to the level of the rib.
- There is no benefit to subcutaneous tunneling of the thoracostomy tube. Not only is tunneling more difficult, but it also increases the chances of tube kinking and chest wall or intercostal bleeding and does not reduce the risk of empyema. Direct entry into the pleural space is preferred.
- A Kelly clamp is advanced, in a “pushing and twisting” fashion, along the superior aspect of the rib until a “pop” is felt and the pleural space is entered. The physician’s second hand should be used to brace the Kelly clamp and avoid inadvertent damage to the underlying lung or heart.
- The Kelly clamp is opened to create a pathway large enough for a finger to pass.
- The physician’s finger is inserted through the incision, into the pleural space, and swept along the thoracic wall to evaluate for adhesions.
- The thoracostomy tube is grasped with a clamp through its distal fenestration. The distal end of the tube is clamped to avoid splashing of blood on healthcare staff. The tube is guided through the incision with a Kelly clamp into the pleural cavity. As soon as it enters the cavity, the clamp is released and withdrawn, while the tube is advanced in a twisting fashion posteriorly and towards the apex of the hemithorax.
- The tube is then rotated about 360° to reduce the risk of kinking or placement in the fissure of the lung.
- In an adult patient, the tube should be placed at roughly 8–12 cm depth to the skin incision, ensuring that all tube fenestrations are in the pleural cavity.
- The tube is then secured to the skin with a 0-silk suture. A horizontal mattress suture can be placed around the tube and left untied to close the incision after chest tube removal. If the skin incision at the insertion site is too long, it should be closed around the tube with interrupted sutures. The tube is further secured to the thoracic wall with adhesive tape.
- The thoracostomy tube is then connected to a pleurovac with −20 mm H_2O pressure.
- A follow up chest X-ray should be obtained to ensure correct placement of the tube.

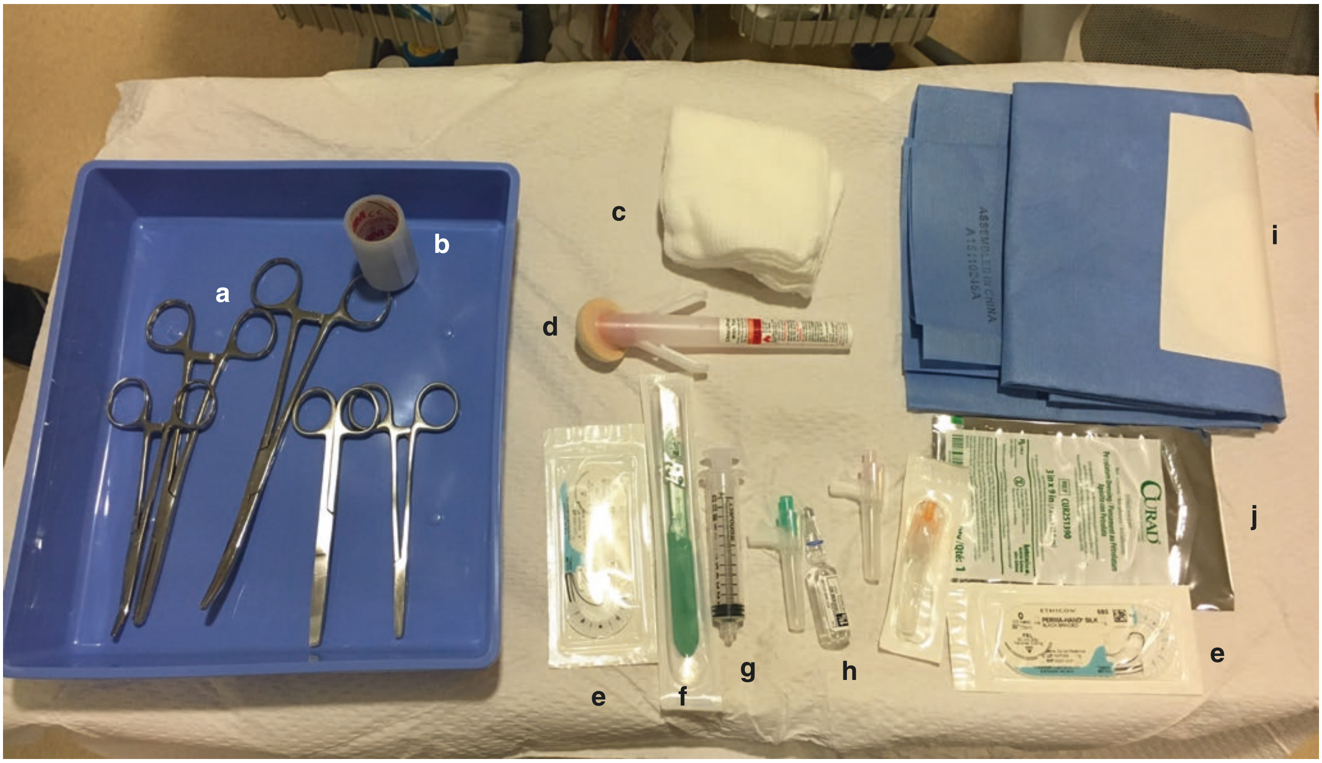


Fig. 8.2 Thoracostomy tube insertion instrument tray. A—clamps, scissors, and needle driver. B—tape. C—sterile gauze. D—Chlorhexidine swab. E—Suture for securing chest tube. F—15 blade scalpel. G—10 cc syringe. H—Vial of lidocaine and needles for injection. I—sterile drape. J—Xeroform gauze

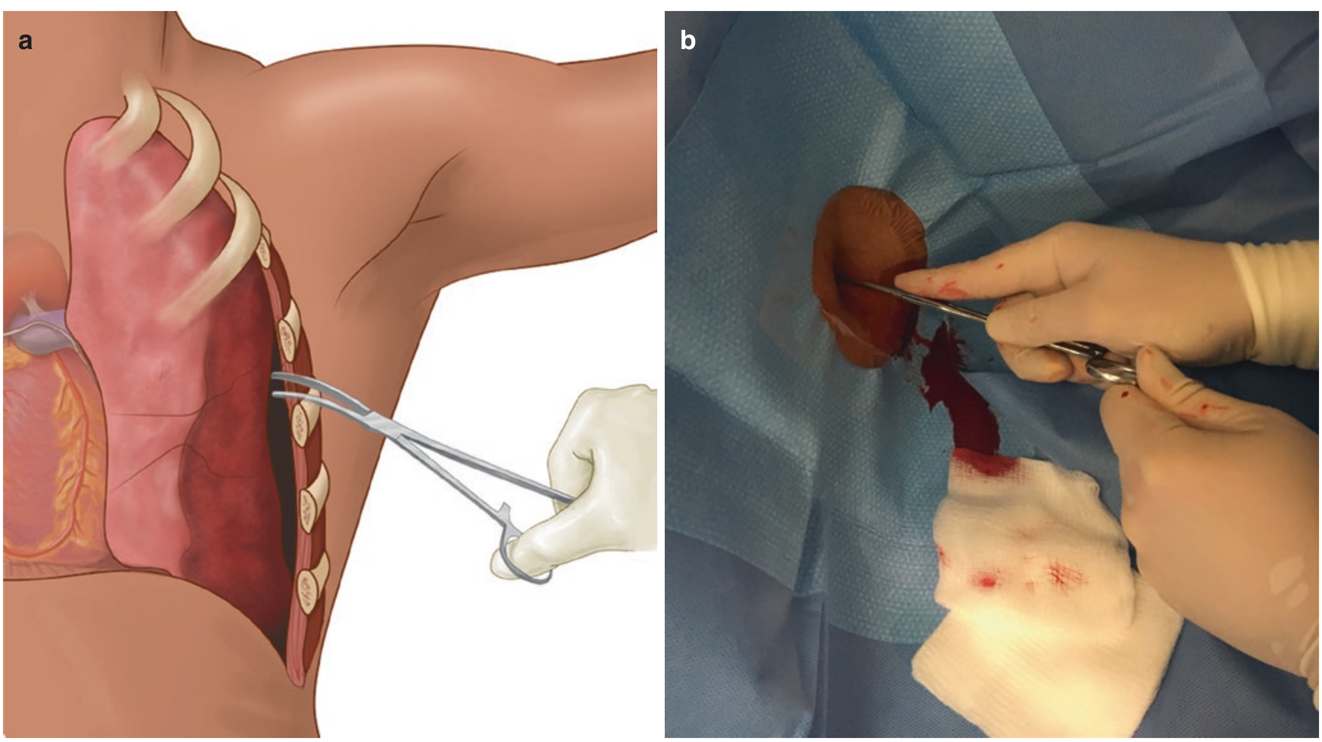


Fig. 8.3 (**a**, **b**) A Kelly clamp is inserted into the pleural cavity, over the superior aspect of the rib. (**c**) The Kelly clamp is opened as it is withdrawn to create a tunnel in the intercostal muscle and subcutaneous tissue. (**d**, **e**) A finger is inserted into the pleural cavity and swept along the thoracic wall to ensure positioning and that the lung is not adherent

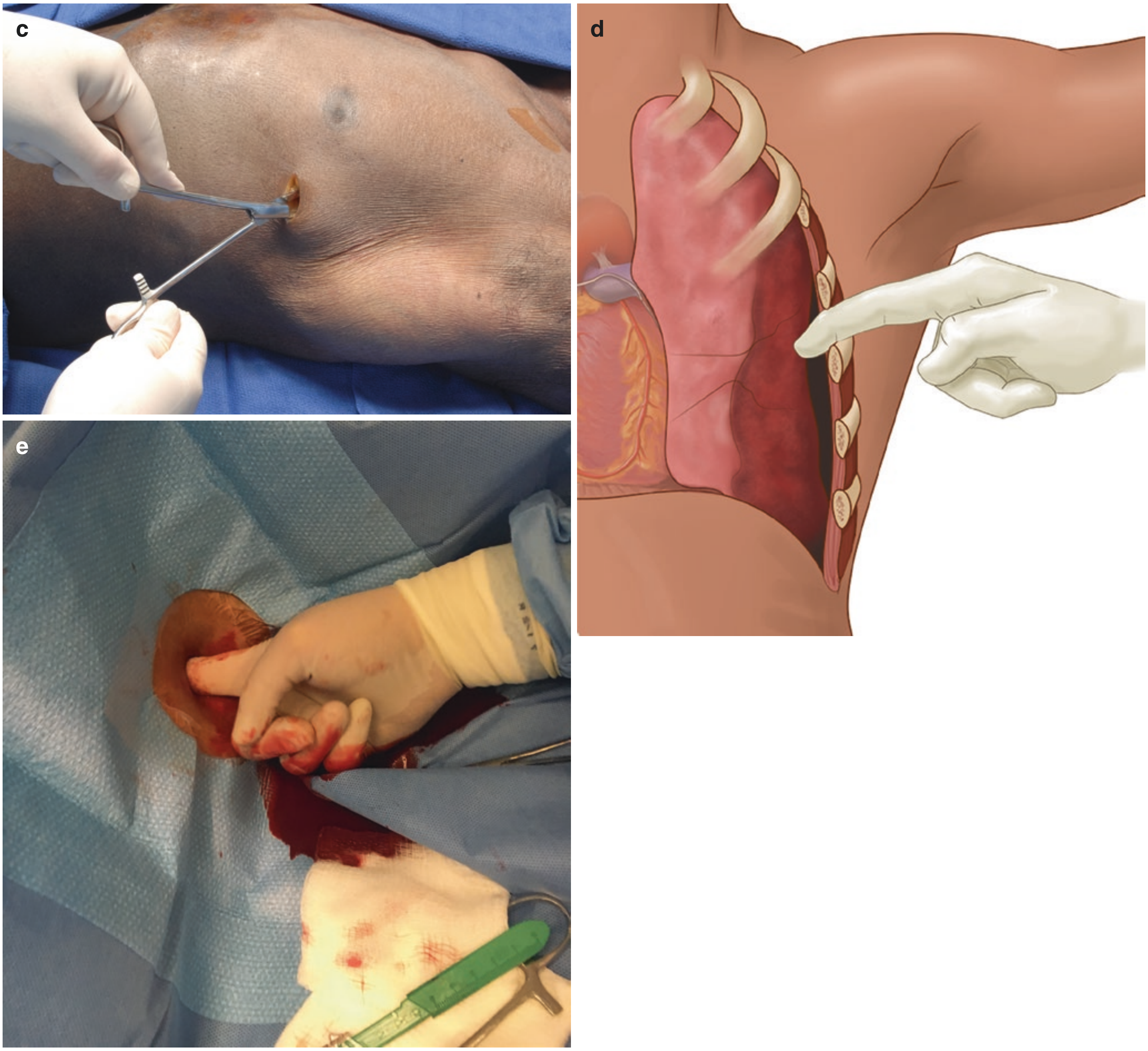


Fig. 8.3 (continued)

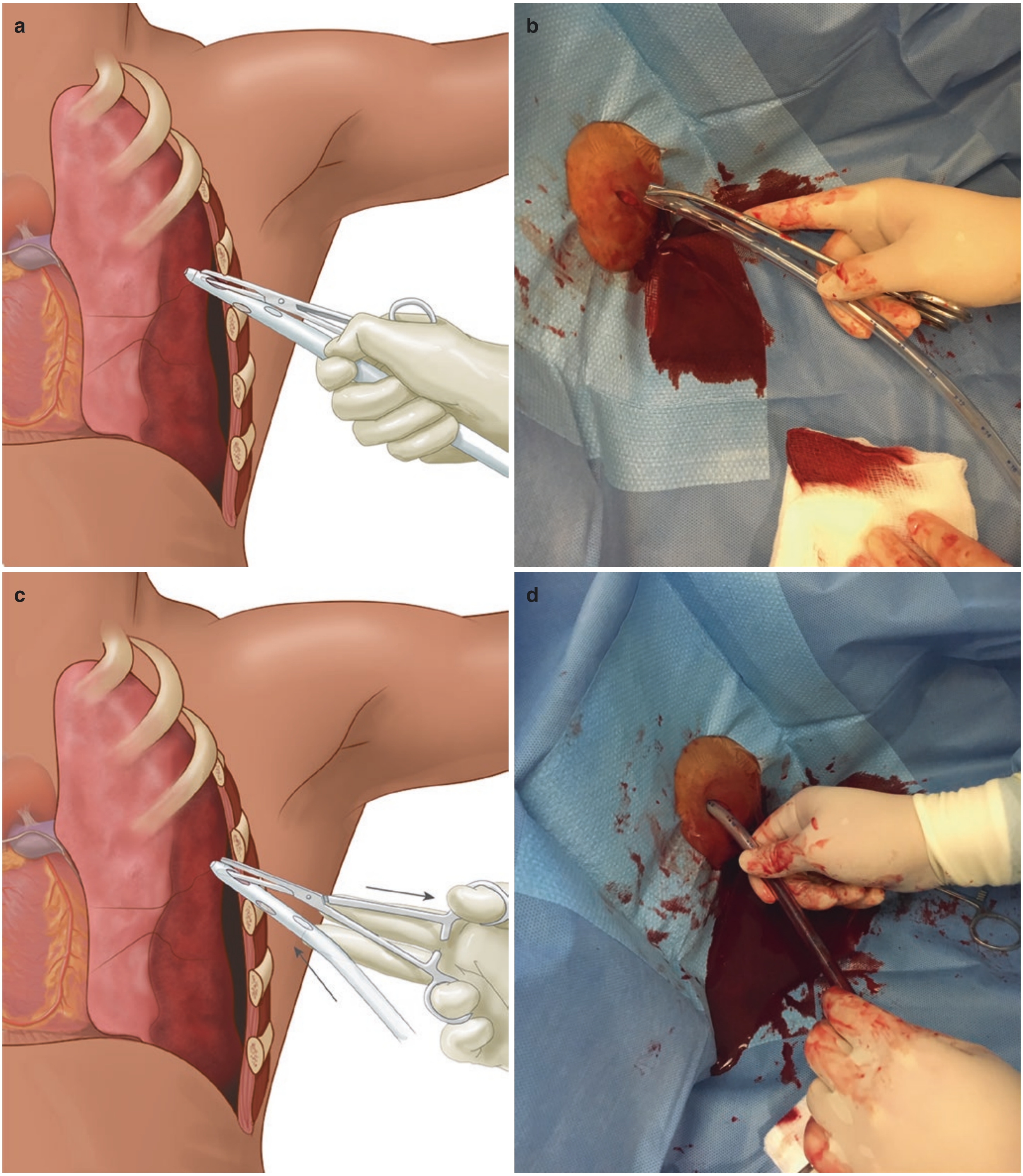


Fig. 8.4 (**a**, **b**) The thoracostomy tube is grasped with a Kelly clamp through its distal fenestration and inserted into the pleural cavity, using a pushing and rotating movement. (**c**, **d**) Once the tube is in the thoracic cavity, the Kelly clamp is withdrawn and the thoracostomy tube is advanced further to 8–10 cm. Ensure that the distal fenestration is within the thoracic cavity

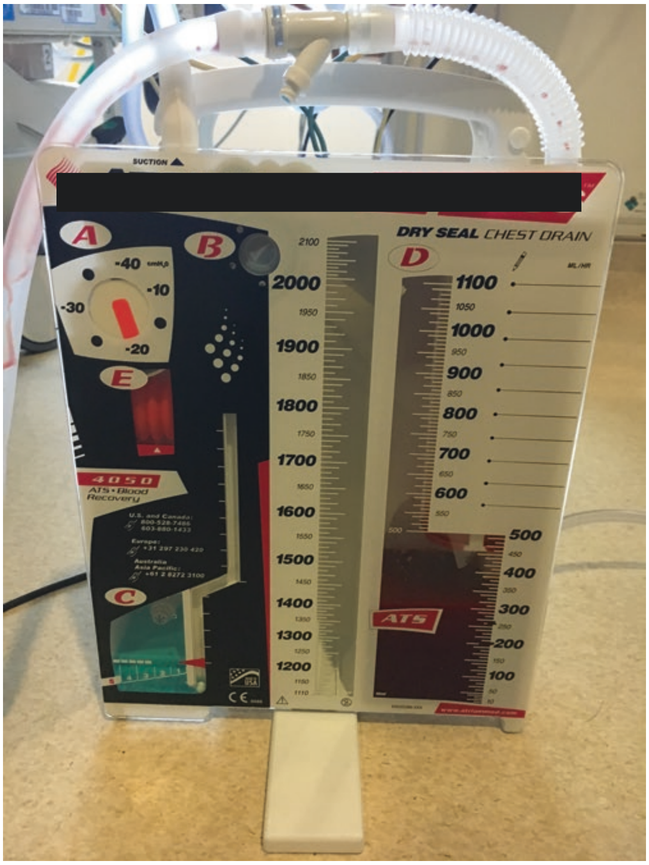


Fig. 8.5 A Pleurovac is connected to the thoracostomy tube with −20 cm H_2O pressure

8.5 Percutaneous Technique

- The percutaneous technique is less painful than the open technique.
- Similarly to the open technique, it is important to use aseptic precautions and local anesthetic infiltration with lidocaine with 1% epinephrine.
- The introducer needle, attached to a syringe with sterile saline, is slowly advanced through the skin and intercostal muscle to the pleural space until fluid or air return is obtained in the saline-filled syringe.
- The needle should be directed along the superior aspect of the rib to avoid inadvertent injury to the intercostal vessels. Aim slightly posteriorly and towards the apex of the hemithorax.
- The syringe is then removed and a guidewire is inserted through the needle. It is important to maintain control of the guidewire at all times.
- The needle is then removed, leaving the guidewire in place.
- A small incision, the size of the diameter of the chest tube, is then made on the skin overlying the guidewire.
- Tissue dilators are serially inserted over the guidewire.
- The chest tube is then advanced over the wire into the pleural space and the guidewire is removed.
- The tube is secured to the skin with a 0-silk stitch.
- The tube is connected to a pleurovac with −20 cm H_2O pressure and a follow-up chest X-ray is obtained to ensure correct placement.
- Instruct the patient to cough and take deep breaths while sitting up and lying on the back and sides for early re-expansion of the lung and drainage of the hemothorax before blood clotting.

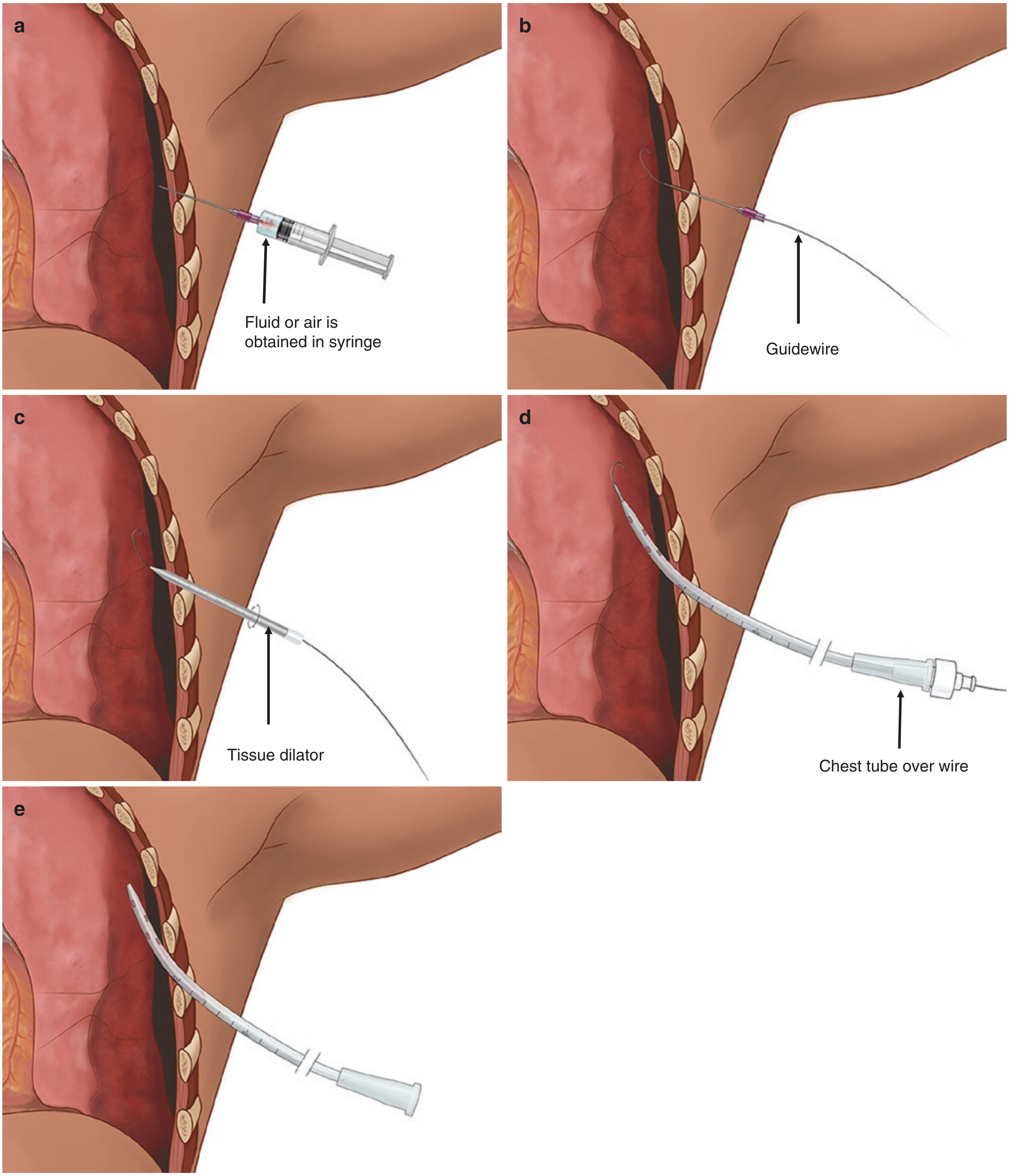


Fig. 8.6 (**a**) A needle attached to a syringe filled with saline is inserted into the pleural space, over the superior border of the rib, through the fourth or fifth intercostal space, until fluid or air is aspirated. (**b**) The guidewire is advanced through the introducer needle into the pleural space. (**c**) The subcutaneous tissue and intercostal muscle are dilated with the tissue dilator over the wire. (**d**) The thoracostomy tube is advanced with a direction towards the apex of the hemithorax and posteriorly over the guidewire into the pleural space. (**e**) The wire is removed, leaving the thoracostomy tube in place

8.6 Chest Tube Removal

- A thoracostomy tube may be removed when the pneumothorax has resolved, when there is no air leak from the tube, and when the output of the tube is less than 50–100 mL per day. The duration of the chest tube is an independent risk factor for empyema.
- To remove a chest tube, the dressing and suture are first removed. A dressing of gauze and petroleum jelly coated gauze is held over the site of chest tube insertion. The tube is quickly pulled during deep inspiration or deep expiration and the dressing is placed over the incision. It is kept in place with silk tape and left for 48 h before removal.
- A follow up chest X-ray is often obtained to ensure no residual pneumothorax.

8.7 Autotransfusion

- Autotransfusion should be considered in patients with a large hemothorax. It provides warm, matched whole blood to the patient in a timely manner.
- 1 mL of sterile sodium citrate solution is injected into the Pleurovac per 10 mL blood to maintain anticoagulation.

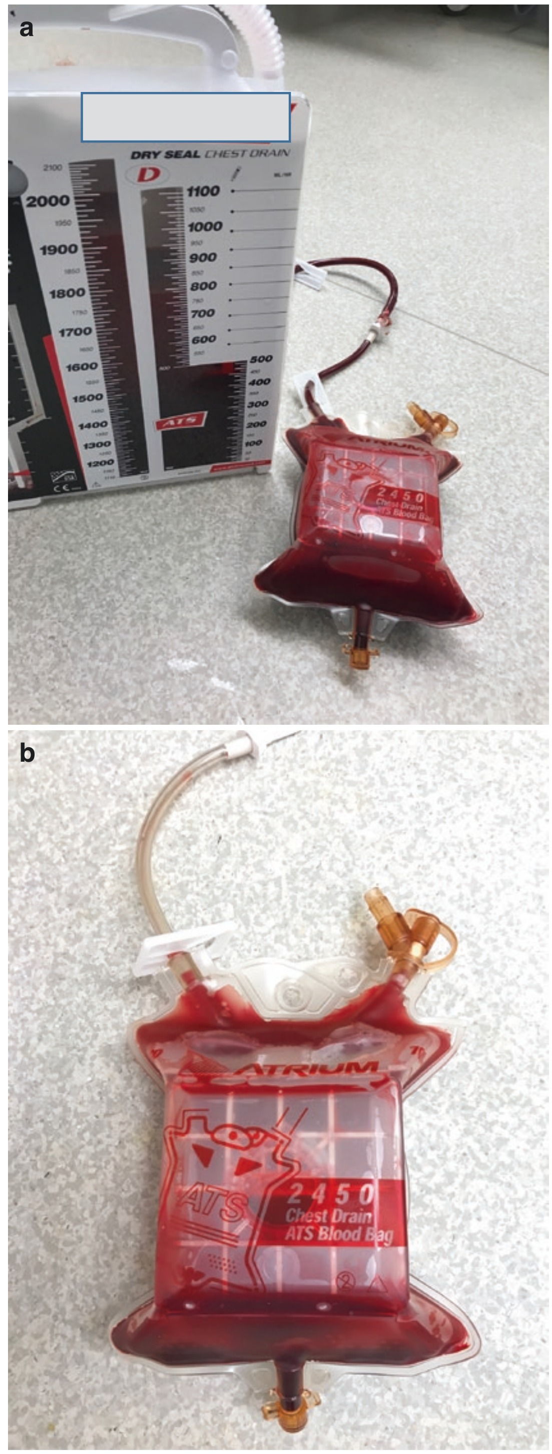


Fig. 8.7 (**a**, **b**) Autotransfusion system. The collected blood can be transfused directly to the patient, using standard blood transfusion procedures

8.8 Residual Hemothorax

- Residual hemothorax is defined as retained blood >300–500 mL after initial insertion of a chest tube. Undrained significant residual hemothorax may aggravate the respiratory function in patients with compromised respiratory physiology, increase the risk of empyema, and may cause delayed fibrothorax and lung entrapment.
- Chest plain film is unreliable in diagnosing the presence and size of residual hemothorax. No major therapeutic decisions should be made exclusively on chest X-ray. The definitive diagnosis should be made by CT scan.
- Small residual hemothoraces (<300 mL) can safely be observed and they are usually absorbed. Large residual hemothoraces (>300 mL) should be evacuated as soon as possible. Delaying the definitive evacuation for more than 7 days makes any therapeutic intervention less likely to be successful and increases the risk of complications.
- The first step in managing a residual hemothorax is to replace any malpositioned tubes. Blindly inserting a second or third tube is rarely successful and increases the risk of empyema. Image-guided percutaneous drainage should be used for additional drains, especially in loculated collections.
- Intrapleural thrombolysis with 25 mg TPA or 100,000 units urokinase in 50 mL normal saline via chest tube should be considered early, within 3–4 days of the diagnosis of residual hemothorax. Following the instillation of the thrombolytic agent, the chest tube is clamped for 4 h and the patient ambulated if possible. The tube is then unclamped and connected to suction. The process may be repeated daily for three consecutive days. Contraindications to thrombolysis include major trauma or major surgery within 48 hours, severe head or spinal injury within 30 days, and recent solid organ injury treated non-operatively.
- If thrombolysis fails, the next step is video-assisted thoracoscopy (VATS), ideally with 7 days of the diagnosis of the residual hemothorax, before the clot is organized.
- Delayed evacuation of a residual hemothorax may require thoracotomy and possible decortication of the entrapped lung.

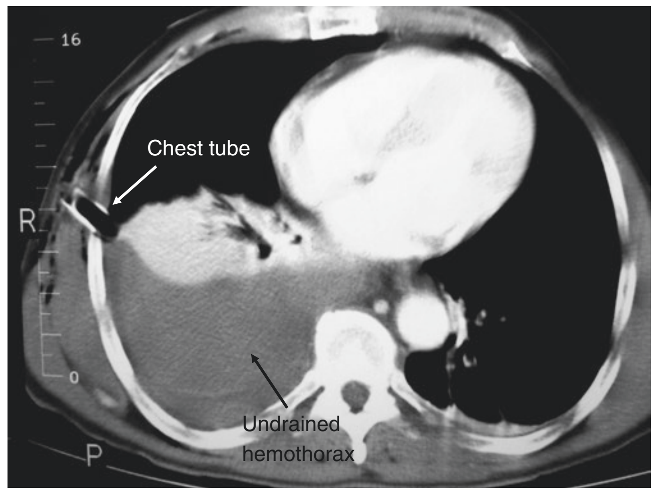


Fig. 8.8 A right thoracostomy tube in place with a significant retained hemothorax

8.9 Tips and Pitfalls

- Insertion of the thoracostomy tube with the use of a trocar is associated with an increased risk of iatrogenic injuries.
- Injury of the intercostal vessels during insertion is rare but it may occur if the insertion site is very close to the inferior border of the rib. This bleeding usually slows and stops on its own, but may occasionally require removal of the tube and occlusion of the bleeding vessel with a Foley catheter balloon and rarely embolization or thoracotomy for surgical ligation.
- Tube misplacement is the most common complication. Tubes placed too far into the thoracic cavity can cause iatrogenic injuries or can kink and result in poor drainage. Thoracostomy tubes should not be inserted deeper than 8–12 cm.
- Iatrogenic injury to the lung, heart, or great vessels can be avoided by judicious use of force when entering the pleural space or inserting the thoracostomy tube.
- Placement of the tube below the fourth to fifth intercostal space may cause iatrogenic injury to the diaphragm, liver or the spleen. It is important to stay at the fourth or fifth intercostal space.
- A persistent air leak is often due to technical problems, such as malpositioning of the tube fenestrations outside the chest cavity or the incision around the tube not being tightly sealed. Persistent air leaks in properly placed tubes may be due to a lung laceration or tracheobronchial injury. Endoscopic evaluation may be needed in persistent leaks, especially in patients with extensive mediastinal emphysema or failure of the lung to expand.
- If a chest tube is being placed for a simple pneumothorax, a smaller 16–18 gauge tube can be inserted and is generally more comfortable for the patient.
- Encourage the patient to cough while sitting up and in supine and lateral positions to promote lung re-expansion and drainage of blood before it clots in the chest cavity.
- Evaluate suspected residual hemothorax by CT scan as soon as possible. Do not make any therapeutic decisions exclusively on the basis of plain chest films.
- Avoid inserting additional chest tubes in a residual hemothorax without radiological guidance. It is potentially dangerous!

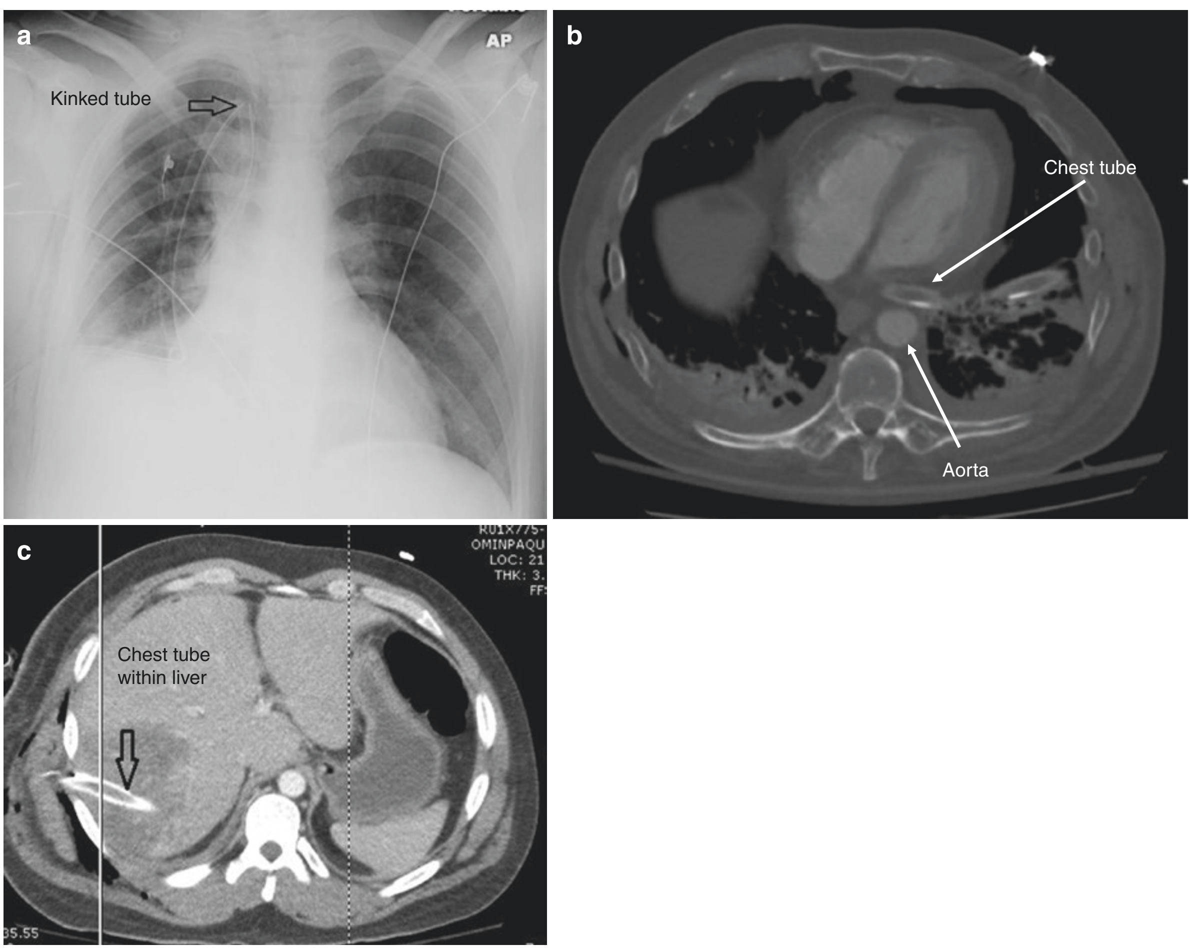


Fig. 8.9 (**a**) A malpositioned right thoracostomy tube that kinks at the mediastinum and again at the apex of the thoracic cavity. (**b**) A malpositioned left thoracostomy tube that penetrates the mediastinum and rests just anterior to the aorta. (**c**) A malpositioned right thoracostomy tube that was inadvertently placed into the liver

9 Pigtail Chest Catheter Placement with Ultrasound Guidance

Jennifer Cone, Stuart Schroff, and Kazuhide Matsushima

9.1 General Principles

- A bedside thoracentesis is performed for both diagnostic and therapeutic purposes in patients with pleural effusions.
- The needle should be advanced just above the superior aspect of the rib to avoid injuries to the neurovascular bundle (intercostal artery, vein, and nerve) (Fig. 9.1).
- The use of ultrasound for guidance is recommended to reduce the risk of complications.
- A low-frequency (3.5–5 MHz) ultrasound transducer is best suited for thoracentesis.
- The patient should be evaluated for any risk factors (e.g., coagulopathy).

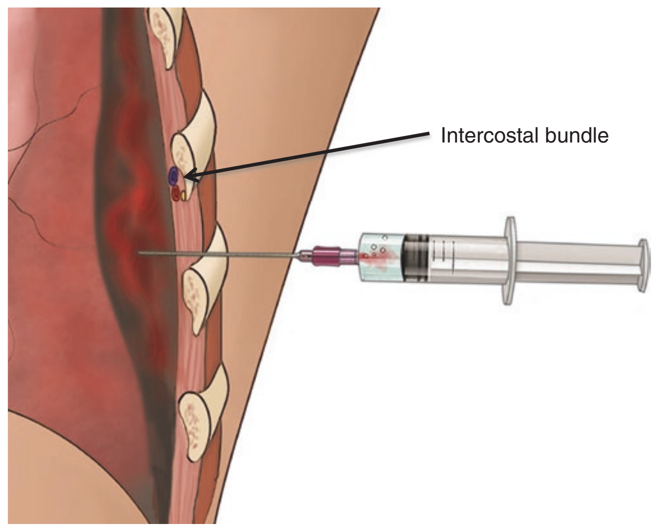


Fig. 9.1 The neurovascular bundle is located at the inferior border of the rib. The needle should always be inserted at the superior border of the rib to avoid injury to the bundle

J. Cone · K. Matsushima (✉)
Division of Acute Care Surgery, University of Southern California, Los Angeles, CA, USA
e-mail: Kazuhide.matsushima@med.usc.edu

S. Schroff
Department of Radiology, University of Southern California, Los Angeles, CA, USA

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_9

9.2 Sonographic Anatomy

- Knowledge of the normal ultrasound appearance of the chest wall, pleura, and adjacent structures is essential for safe thoracentesis (Fig. 9.2).
- Pleural fluid appears as an anechoic area (black) or hypoechoic area (gray) above the diaphragm. The atelectatic lung is identified as a hyperechoic structure (white).

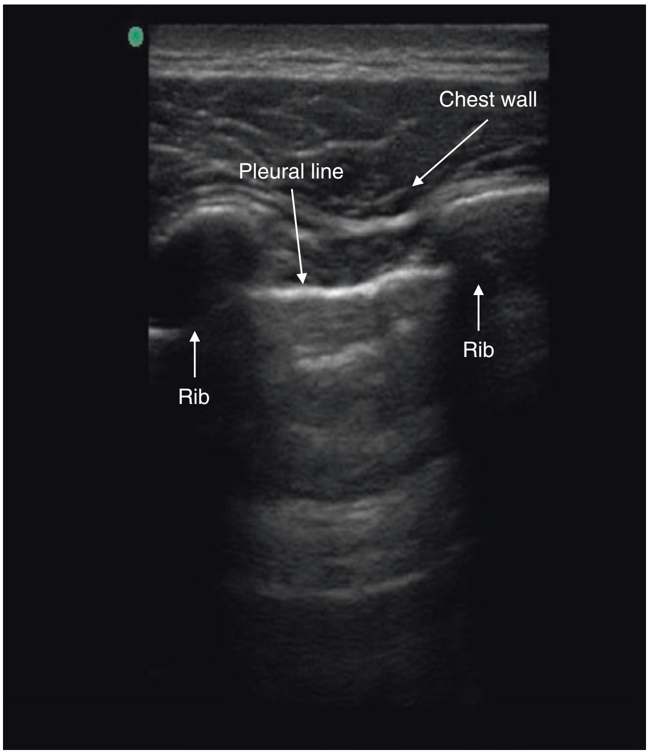


Fig. 9.2 Normal ultrasound image of the thorax. Sliding of the parietal and visceral pleura can be observed between the ribs

9.3 Patient Positioning

- Intubated patients should be positioned supine in the bed with the arm abducted at 90°.
- Alert and cooperative patients can be positioned in a seated position with the arms rested on a bedside table.

9.4 Site of Insertion

- The fifth to seventh intercostal space is ideal for thoracentesis. A higher insertion site risks inadequate fluid drainage. A lower insertion site risks intra-abdominal insertion and diaphragm or solid organ injury.
- The mid- to posterior axillary line is used for thoracentesis.
- Prior to starting the thoracentesis procedure, it is important to clarify the anatomic relationship between the diaphragm, liver, spleen, and fluid collection using ultrasound.

9.5 Procedure

- The physician should be dressed in a surgical cap and mask with a sterile gown and sterile gloves.
- It is important to maintain strict aseptic technique through the entire procedure to reduce the risk of an infected effusion. A single dose of cefazolin may be given prior to the procedure. Longer antibiotic prophylaxis is not necessary.
- The skin is prepped with chlorhexidine. The chosen insertion site is squared off with sterile towels, or a standard sterile drape can be used.
- The ultrasound probe should be covered with a sterile sleeve. Sterile ultrasound gel is placed inside the sleeve prior to insertion.
- The ultrasound probe is generally held perpendicular to the thoracic wall and in a parallel fashion to the ribs to allow an optimal viewing window (Fig. 9.3).
- Local anesthetic, such as 2% lidocaine with epinephrine, is injected with a 21 gauge needle to create a skin wheel at the planned needle insertion site. The anesthetic then should also be injected into the intercostal muscle, periosteum, and parietal pleura to provide adequate analgesia.
- With a low-frequency (3.5–5 MHz) transducer, the fluid will appear as with low echogenicity (black) in the chest cavity. Hematoma, empyema, or loculated fluid collections may contain echogenic debris. The setting of ultrasound images (gain and depth) should be adjusted at the beginning of examination (Fig. 9.4).
- Once a fluid collection is identified, the introducer needle attached to a syringe is advanced over the superior aspect of the chosen rib (inferior aspect of the intercostal space), avoiding the neurovascular bundle on the inferior aspect of the rib (superior aspect of the intercostal space).
- Under ultrasound guidance, the tip of the needle will be visualized with high echogenicity (white) (Figs. 9.5 and 9.6).
- The syringe is drawn back with negative pressure as the needle is advanced until fluid returns in the syringe. The needle should then be held in place, and the syringe is removed.
- For patients who require continuous drainage of pleural effusion, a pigtail chest drainage catheter can be placed (see chapter 10) (Fig. 9.7a, b).
- Catheter tubing is connected to the needle. Depending on how quickly the chest fluid is to be removed, the catheter tubing is then connected to a negative-pressure vacuum container, a closed-chest drainage system, or a simple gravity drainage bag (Fig. 9.8a–c).
- Draining more than 1.5–2 L of fluid under negative-pressure vacuum at one time increases the chance of lung re-expansion pulmonary edema.
- It is important to maintain control of the needle the entire time it is in the pleural cavity.
- When fluid slows or stops, the needle can be removed. The insertion site is covered with gauze. A follow-up chest radiograph is obtained to ensure adequate fluid removal and no pneumothorax.

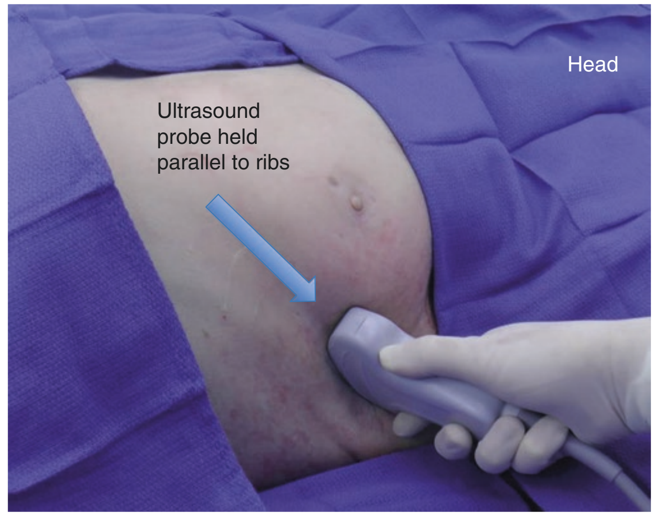


Fig. 9.3 An ultrasound probe is applied perpendicular to the thoracic wall between the ribs

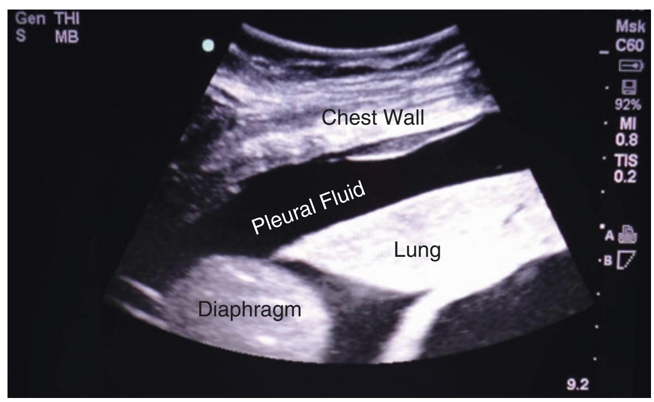


Fig. 9.4 A large pleural effusion is seen on ultrasound image. Note the inferior aspect of the lung and the diaphragm.

Fig. 9.5 An ultrasound probe should be kept in place for the guidance while a needle enters the pleural cavity

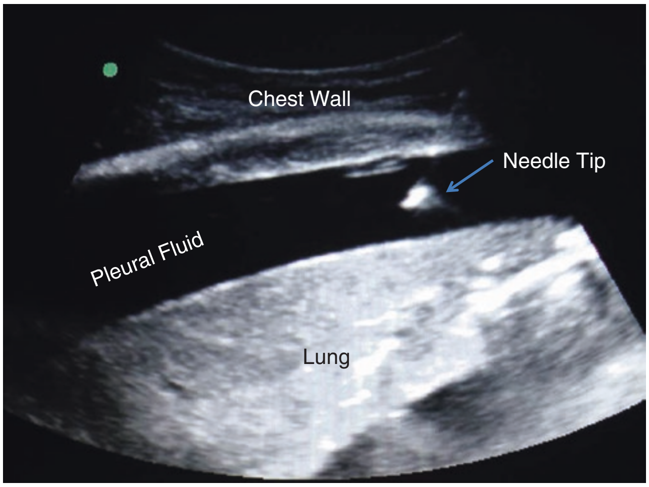


Fig. 9.6 The hyperechoic needle can be seen entering a pleural effusion on ultrasound image

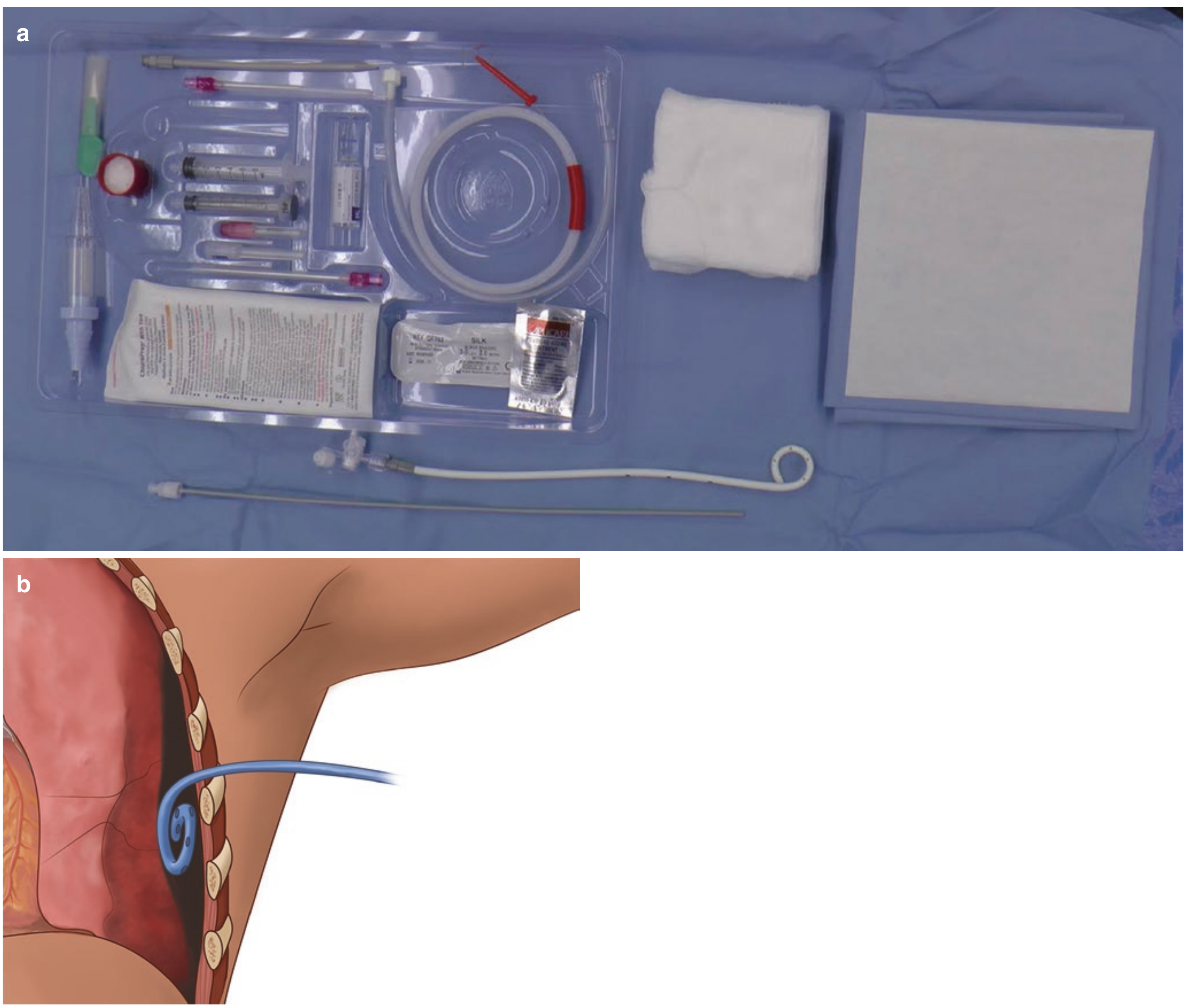


Fig. 9.7 (**a**, **b**) Commercially available pigtail drainage catheter kit (**a**). Pigtail catheter in pleural cavity (**b**)

Fig. 9.8 (**a**–**c**) A drainage needle or catheter can be connected to a gravity drainage bag (**a**), a negative-pressure vacuum container (**b**), or a closed-chest drainage system (**c**)

9.6 Tips and Pitfalls

- It is important to stay at the fifth to seventh intercostal space to allow for adequate drainage and avoid iatrogenic injury of the diaphragm, the liver, or the spleen. Ultrasound should be used for guidance particularly in the case with loculated pleural fluid.
- Iatrogenic injury to the lung, heart, or great vessels can be avoided by judicious use of force when entering the pleural space with the needle.
- Injury of the intercostal vessels during insertion is rare, but it may occur if the insertion site is very close to the inferior border of the rib. This bleeding usually slows and stops on its own but may occasionally require removal of the tube and occlusion of the bleeding vessel with a Foley catheter balloon and rarely embolization or thoracotomy for surgical ligation.

10 Percutaneous Dilational Thoracostomy Catheter and Heimlich Valve Placement

Jennifer Cone and Kazuhide Matsushima

10.1 General Principles

- Percutaneous thoracostomy catheters can be used for both short- and long-term drainage.
- A pigtail catheter is a good choice for prolonged pleural drainage, while straight catheters are best for short-term drainage.
- Heimlich valves are one-way valves that allow drainage of fluid or air from the pleural cavity upon expiration without allowing air to reenter on inspiration.
- The Heimlich valve can replace pleurovac drainage systems in select patients and can allow for more mobility.
- The Heimlich valve works best for air and simple fluid. Blood or thick purulent fluid can cause malfunction of the valve system.
- For a pneumothorax, the catheter can be placed either in the midclavicular line in the second or third intercostal space or in the midaxillary line in the fourth or fifth intercostal space.
- For a pleural effusion, the catheter should be placed in the midaxillary line in the fourth or fifth intercostal space.

J. Cone · K. Matsushima (✉)
Division of Acute Care Surgery, University of Southern California, Los Angeles, CA, USA
e-mail: Kazuhide.matsushima@med.usc.edu

10.2 Procedure

10.2.1 Percutaneous Catheter Placement

- If pleural effusion drainage is desired for several hours or days, a percutaneous thoracostomy catheter is an option to be considered. Commercially available kits are designed for this process (Fig. 10.1).
- It is safest to perform percutaneous catheter placement under ultrasound guidance. See chapter on Thoracentesis with Ultrasound Guidance for more details.
- It is important to maintain strict aseptic technique through the entire procedure to reduce the risk of an empyema. The physician should take universal precautions, including sterile gown and gloves, cap, and mask.
- A single dose of cefazolin may be given prior to the procedure. Longer antibiotic prophylaxis is not necessary.
- The skin is prepped with chlorhexidine or betadine. The chosen insertion site is squared off with sterile towels, or a standard sterile drape can be used. Sterile drapes should cover the whole body.
- For a pneumothorax, the catheter can be placed either in the midclavicular line in the second or third intercostal space or in the midaxillary line in the fourth or fifth intercostal space.
- For a pleural effusion, the catheter should be placed in the midaxillary line in the fourth or fifth intercostal space.
- Local anesthetic, such as 2% lidocaine with epinephrine, is injected with a 21 gauge needle to create a skin wheel at the planned needle insertion site. The anesthetic then should also be injected into the intercostal muscle, periosteum, and parietal pleura to provide adequate analgesia.
- The introducer needle attached to a syringe is slowly advanced over the superior aspect of the chosen rib, avoiding the neurovascular bundle on the inferior aspect of the rib (Fig. 10.2).
- Depending on the kit available, there may or may not be a sheath present over the introducer needle.

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_10

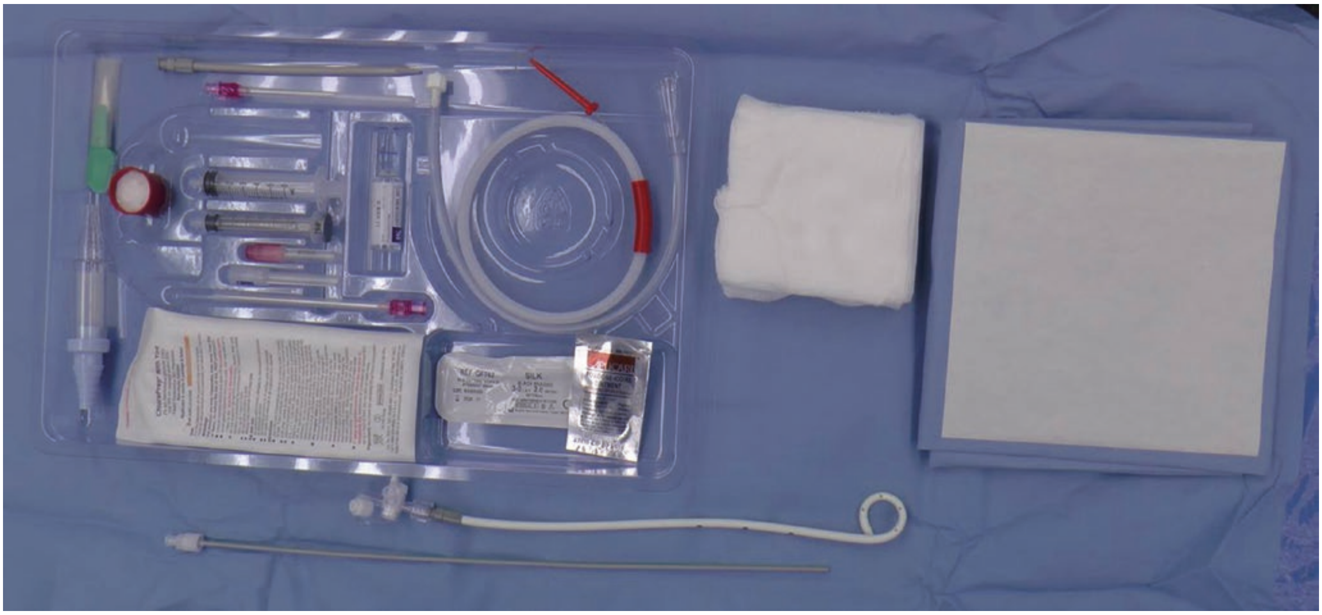


Fig. 10.1 A typical percutaneous catheter insertion kit is shown

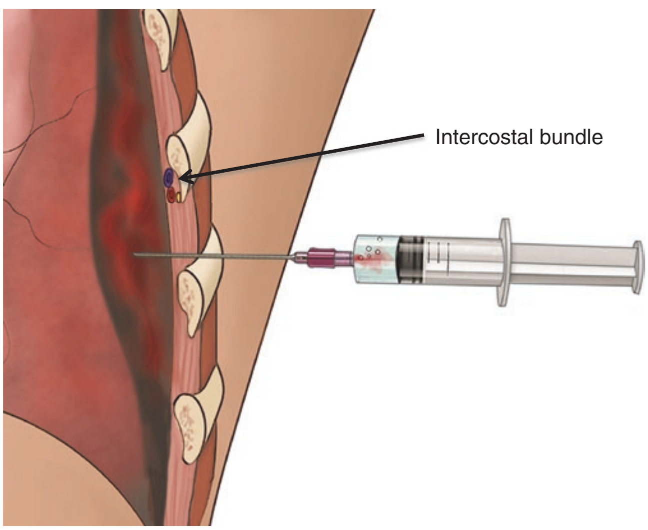


Fig. 10.2 The neurovascular bundle is located at the inferior border of the rib. The needle should be inserted at the superior border of the rib to avoid injury to the bundle

- If a sheath is present, the needle is removed from the chest once fluid or air is obtained, leaving the sheath in place. A guidewire is then advanced into the chest (Fig. 10.3a, b).
- If no sheath is present, the guidewire is advanced through the needle into the chest, and the needle is removed.
- It is important to maintain control of the needle and wire at all times.
- A small incision is then made at the insertion site around the guidewire with a 15- or 11-blade scalpel (Fig. 10.4).
- Tissue dilators are advanced over the wire, through the intercostal muscles. Again, it is important to maintain control of the guidewire at all times (Fig. 10.5a, b).
- If a catheter stiffener is present in the kit, insert it into the percutaneous catheter to straighten the catheter out.
- The catheter is then advanced over the guidewire into the pleural cavity. The guidewire and any catheter stiffeners are removed (Fig. 10.6a, b).
- The catheter is secured into place with sutures. The catheter is connected to the chest drainage system (e.g., Pleur-evac®). Set up for water seal or suction (Fig. 10.7a, b).
- A follow-up chest radiograph is obtained to ensure adequate catheter position and no procedure-related complications.
- The percutaneous catheter may be removed when the pleural effusion has resolved, when there is no air leak from the tube, and when the output of the tube is less than 50–100 mL per day.
- To remove the percutaneous catheter, the dressing and suture are first removed. A dressing of gauze and petroleum jelly-coated gauze is held over the site of chest tube insertion. The tube is quickly pulled with the patient's breath held, and the dressing is placed over the incision. It is kept in place with silk tape and left for 48 h before removal.
- A follow-up chest X-ray is obtained to ensure no residual pneumothorax.

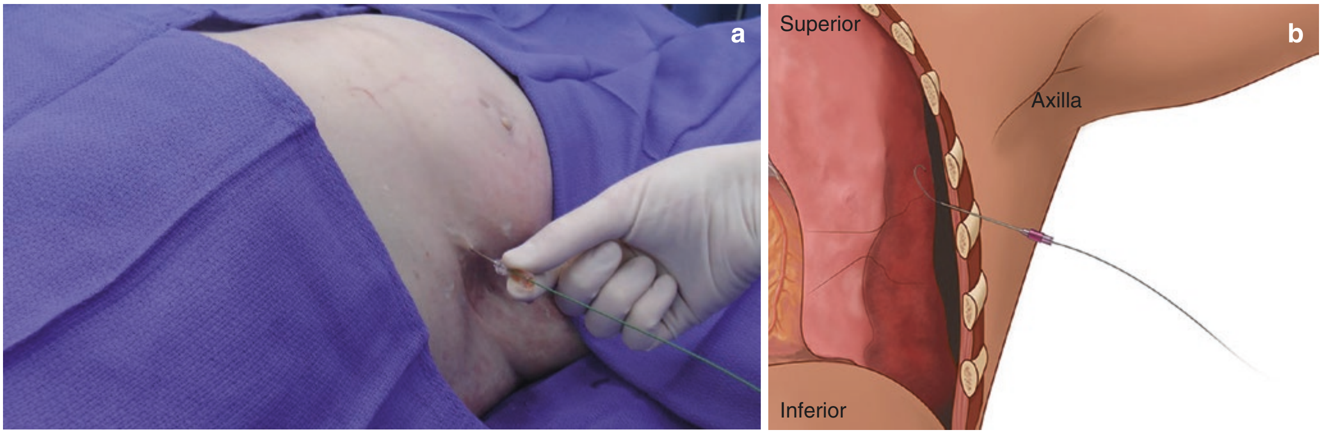


Fig. 10.3 (**a**, **b**) A wire has been inserted through the introducer needle and is shown in place in the thoracic cavity

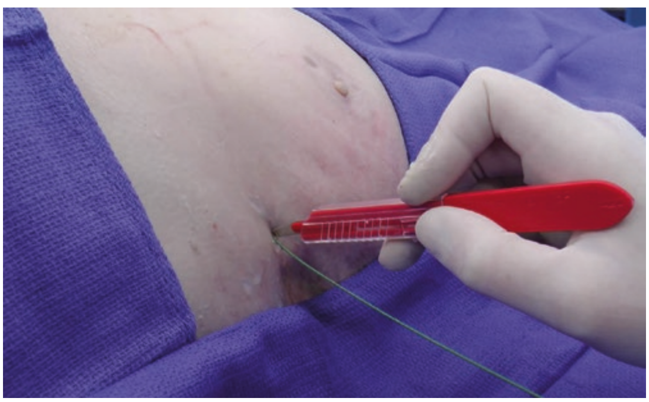


Fig. 10.4 After the introducer needle has been removed, a scalpel is inserted adjacent to the guidewire to create an incision large enough to fit the catheter

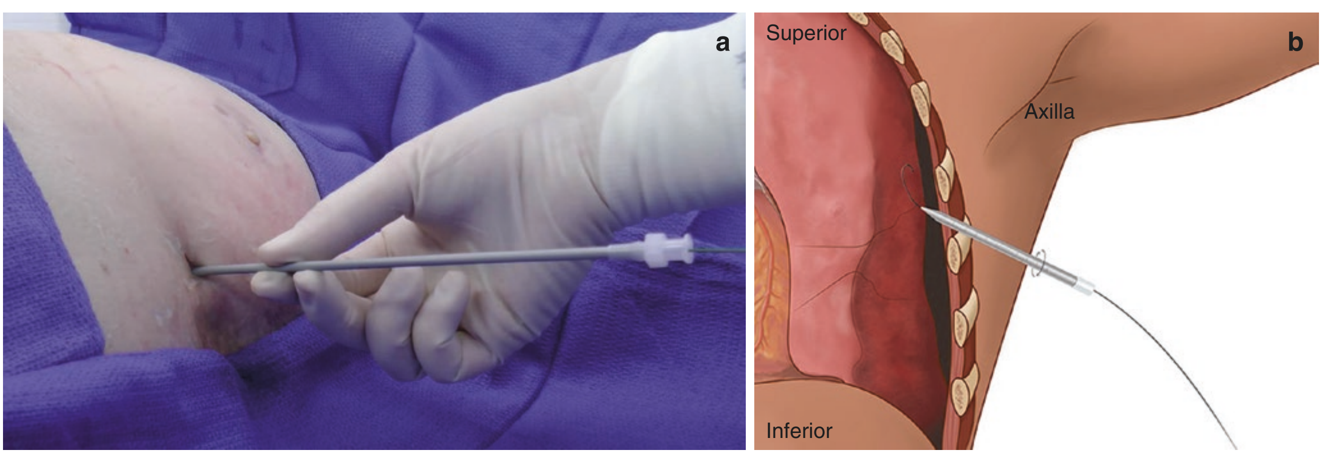


Fig. 10.5 (**a**, **b**) A tissue dilator is inserted over the guidewire, through the skin, subcutaneous tissue, and muscle into the pleural space

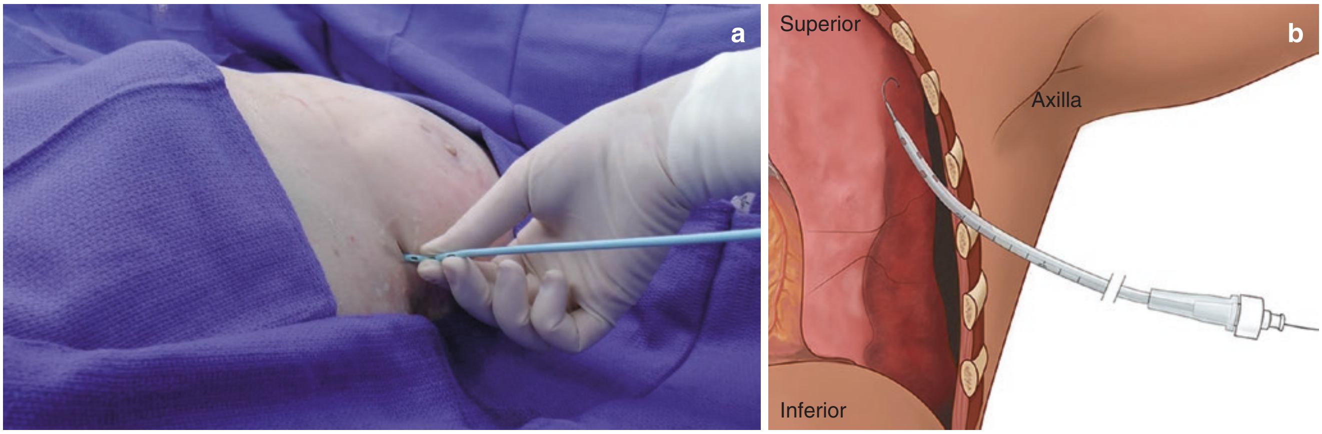


Fig. 10.6 (**a**, **b**) A percutaneous catheter with stiffener is inserted into the pleural space over the guidewire

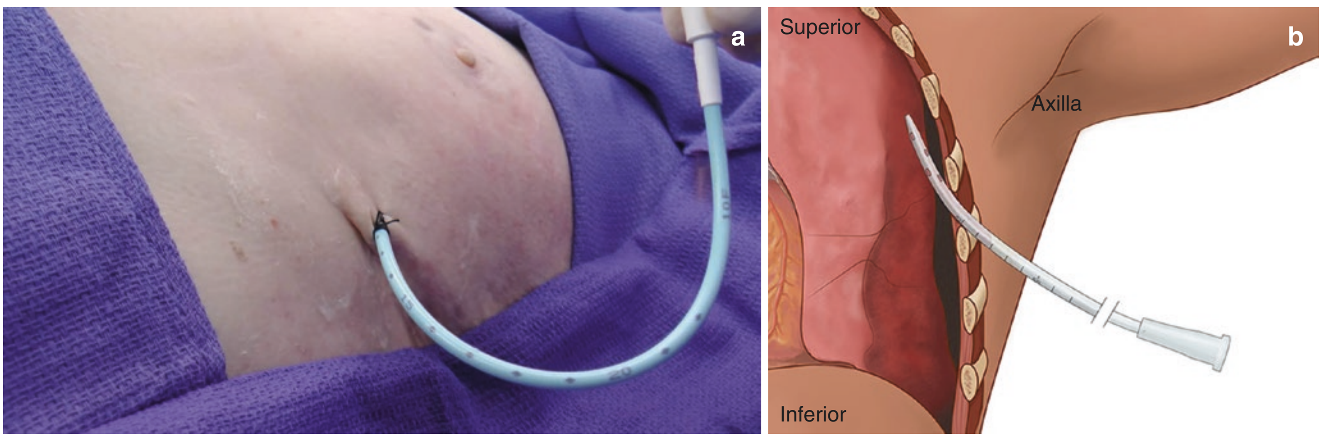


Fig. 10.7 (**a**, **b**) The percutaneous catheter is shown in proper position, sewn into place

10.2.2 Connection to the Heimlich Valve

- Begin by clamping the percutaneous catheter.
- Using sterile technique, the end of the catheter is trimmed to fit the Heimlich valve adapter.
- The open end of the catheter is joined to the blue end of the Heimlich valve. Some Heimlich valves do not have different colors. In this case, attach the open end of the catheter to the end with the attached rubber valve (Fig. 10.8).
- Tape the catheter or chest tube to the valve to prevent dislodgement.
- Connection tubing is attached to the open end of the Heimlich valve, and the tubing is connected to a drainage bag (Fig. 10.9).
- The catheter can then be unclamped.
- Encouraging the patient to cough vigorously will help to eradicate trapped air from the pleural cavity.
- A follow-up chest radiograph can be ordered to ensure no pneumothorax (Fig. 10.10).

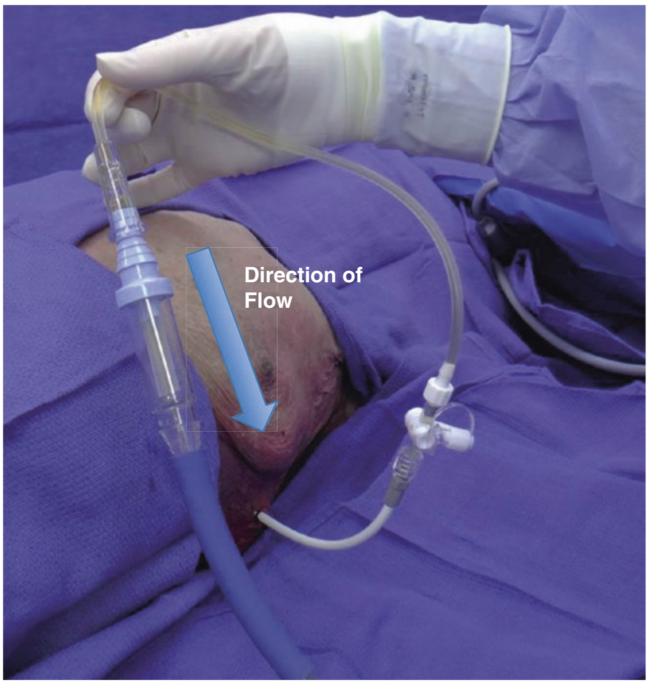


Fig. 10.8 A Heimlich valve is shown specifying direction of proper flow orientation

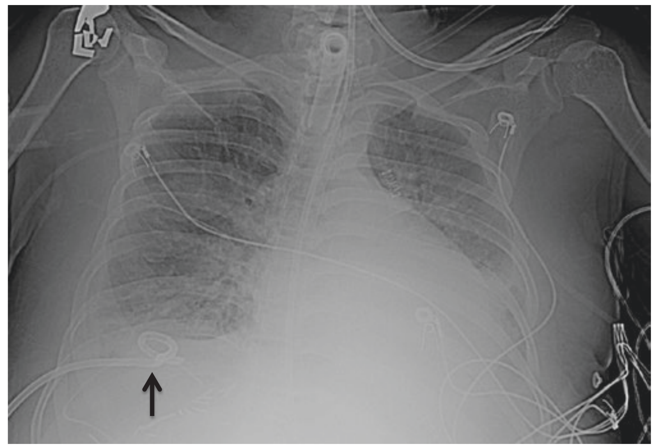
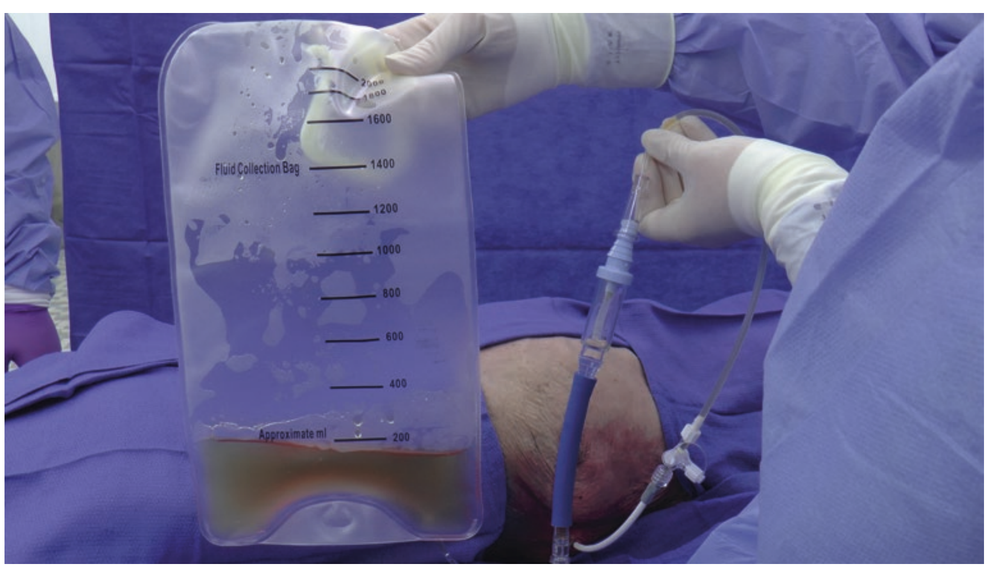


Fig. 10.10 A properly positioned percutaneous catheter is shown on chest radiograph

Fig. 10.9 A collection bag has been attached to the Heimlich valve, and the entire system is shown



10.3 Tips and Pitfalls

- It is important to ensure adequate drainage of pneumothorax after Heimlich valve placement. Any change in clinical condition or shortness of breath should prompt an urgent chest radiograph.
- It is important to ensure proper function of the rubber valve. If draining thick fluid from the chest, the rubber valve can become sticky and fails to work properly. In this case, it is necessary to replace the entire Heimlich valve.
- The valve will pulsate normally as fluid and air escapes. It can also cause a “honking” sound.
- Never occlude the open end of the Heimlich valve. This can worsen pneumothorax.

11 Extracorporeal Membrane Oxygenation (ECMO) Cannulation

Luke Wiggins and Amy Hackmann

11.1 Introduction

- **Extracorporeal membrane oxygenation (ECMO)** is a system where an external circuit carries venous blood from the patient to a gas-exchange device (oxygenator), which then enriches the blood with oxygen and removes carbon dioxide and returns it to the patient circulation.
- ECMO is a well-established adjunct therapy in the pediatric and adult population with life-threatening cardiac or pulmonary failure, not responding to standard therapy.
- There are two modes of ECMO: venovenous (VV) and venoarterial (VA).
- The mode of ECMO is named for the vascular site of the access and return cannula. The access cannula drains blood from the venous system into the ECMO circuit. The return cannula returns the oxygenated blood back to the patient. There are different types of access and return cannulas.
- VV ECMO is used for support in refractory respiratory failure and VA ECMO for refractory cardiac failure.

11.2 General Principles

- Selection of the ECMO modality, venovenous (VV) versus venoarterial (VA) ECMO, is crucial.
- ECMO is not indicated in septic or hypovolemic shock.
- Safe vascular access and cannula selection are key for patient management.

11.3 Indications for VV ECMO

- Hypercapnia with an arterial pH below 7.2
- Hypoxemic respiratory failure with $PaO2:FIO2 < 100$ mmHg despite maximal ventilator support, including nitric oxide, paralytics, or prone positioning

11.4 Indications for VA ECMO

- Refractory cardiogenic shock
- Cardiac arrest from potentially reversible causes
- Failure to wean from cardiopulmonary bypass
- Intractable arrhythmias

11.5 Relative Contraindications to ECMO Support

- Unable to administer anticoagulation (bleeding, recent surgery, recent intracranial injury)
- Irreversible cardiopulmonary disease
- Ineligibility for transplant or ventricular assist device
- Mechanically ventilated for 7 days prior to ECMO
- Poor preexisting functional status
- Neurological damage
- Severe sepsis without source control
- Major bleeding or clotting disorder
- Advanced age
- Chronic multiple organ dysfunction
- Lack of access site(s)
- Unwilling to accept blood transfusions
- Advanced malignancy

11.6 Before Cannulation

- Defibrillator pads should be placed prior to preparing the patient.
- A volume line should be accessible throughout the procedure.
- Cross-matched blood should be available.
- A code cart should be available nearby.

L. Wiggins · A. Hackmann (✉)
University of Southern California, Los Angeles, CA, USA
e-mail: Amy.Hackmann@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_11

11.7 Venovenous ECMO

- VV ECMO is indicated in patients with severe deficits in both oxygenation and ventilation requiring prolonged and aggressive mechanical ventilation strategies. VV ECMO does not, however, provide cardiac or blood pressure support.
- Drainage from the IVC to the pump can be obtained via either femoral vein or from the SVC and IVC using a double-lumen cannula. Return to the patient can be SVC or right atrium via a femoral or IJ cannula.

11.8 Possible VV Cannulation Configurations

A: Drainage from IVC via femoral vein (FV) cannula with return to superior vena cava (SVC) via internal jugular (IJ) vein (Fig. 11.1).

B: Drainage from IVC via FV cannula and return to right atrium (RA) via contralateral FV cannula (Fig. 11.2).

C: Double-lumen cannula in IJV with drainage from SVC and IVC and return to the RA (Figs. 11.3 and 11.4).

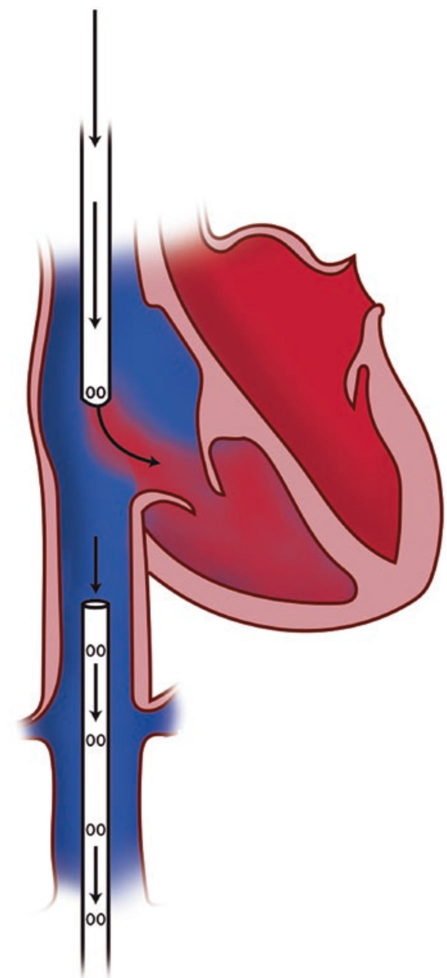


Fig. 11.1 Drainage from inferior vena cava via femoral vein cannula with return to superior vena cava via internal jugular vein

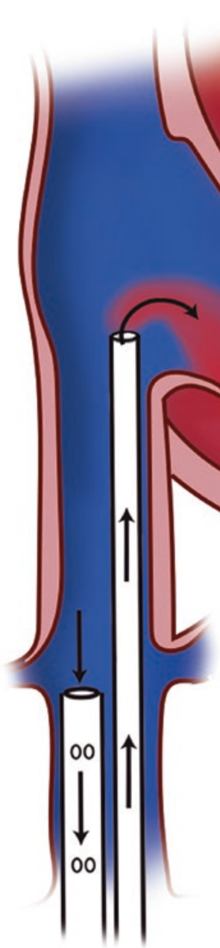


Fig. 11.2 Drainage from inferior vena cava via femoral vein cannula and return to right atrium via contralateral femoral vein cannula

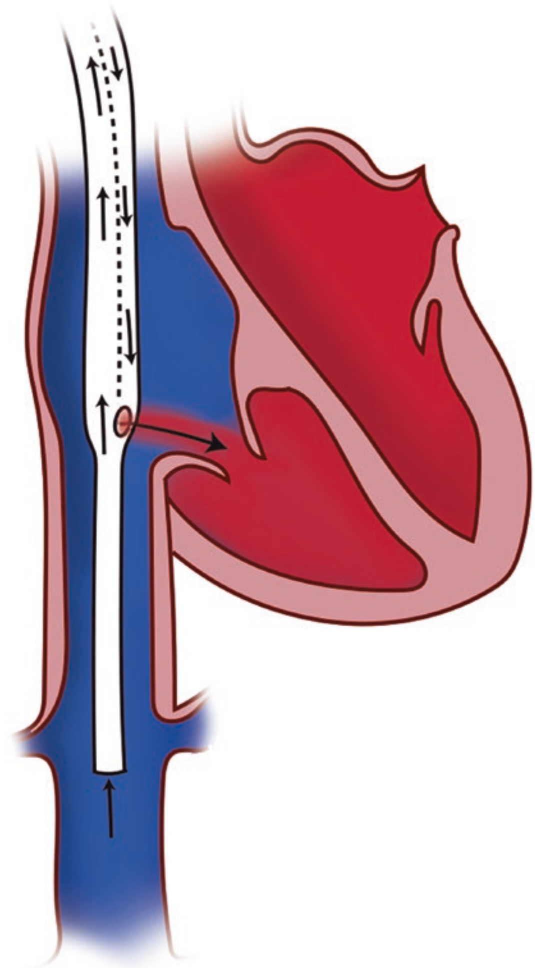


Fig. 11.3 Double-lumen cannula in internal jugular vein with drainage from superior vena cava and inferior vena cava and return to the right atrium

Fig. 11.4 Double-lumen cannula for VV ECMO

11.9 Technique

- With the patient in supine position, both groins and possibly the neck are widely prepped and draped.
- All necessary equipment is assembled (Fig. 11.5).
- Ultrasound guidance for vascular access is recommended (Fig. 11.6).
- For the drainage cannula, the common femoral vein (left, most commonly) is accessed with the introducer needle, and the cannula guidewire is then placed. Ectopy with wire placement is common and confirmatory of venous access.
- The contralateral femoral vein can be used for the return cannula and should be accessed in similar fashion.
- Alternatively, the internal jugular vein can be used for the return cannula. Access into the vein should be low in the neck, approximately 2 cm above the clavicle.
- Once both guidewires are placed, a bolus of anticoagulation can be administered.
- An incision large enough to accommodate the chosen cannula should be made along the tract of the wire.
- Careful serial dilation over the wire using the dilators included with the cannulas or a dilator kit should be performed. Great care should be taken to not bend the guidewire. Gentle tension should be maintained on the wire (Fig. 11.7).
- The sterile, primed tubing of the ECMO circuit should be brought onto the field and secured.
- Beginning with the drainage cannula, it should be advanced over the wire into proper position, usually 40 cm in an average adult. A twisting motion may be necessary to pass the cannula through the soft tissue of the groin (Fig. 11.8).
- The introducer and guidewire are pulled back swiftly, and the cannula is then clamped and deaired.
- An air-free connection under a continuous stream of saline is made between the circuit and the cannula (Fig. 11.9).

Fig. 11.5 All necessary equipment is prepared prior to beginning cannulation

Fig. 11.6 Ultrasound guidance is used to access the target vessels. Guidewires are placed

Fig. 11.7 Serial dilations over a wire for cannula placement. Great care must be taken to avoid bending the guidewire

- The same steps should be taken for the return cannula.
- A purse-string suture incorporating the soft tissue incision should be used to secure the entry site of each cannula.
- Support can then be slowly initiated, watching for color change as the blood passes through the oxygenator. Sweep gas should be equal to flow and later adjusted based on arterial blood gas (Fig. 11.10).
- Additional sutures are placed along the length of the cannula to prevent dislodgement.
- Confirm proper cannula placement with CXR and/or KUB.

Fig. 11.8 An assistant holds the cannula, allowing it to pass over the guidewire. Sometimes a twisting motion is necessary as the subcutaneous tissues are encountered

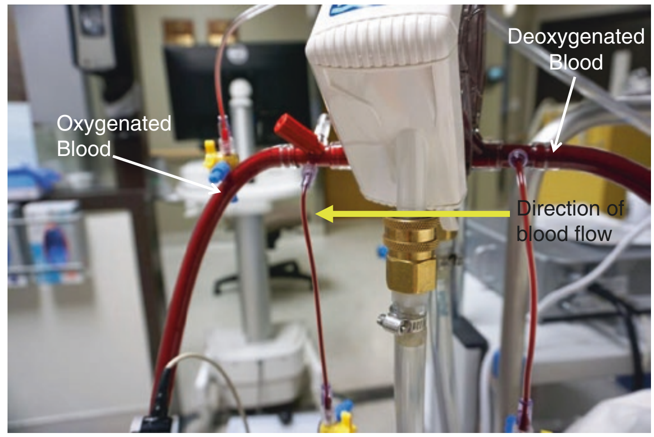


Fig. 11.10 Blood flowing through the oxygenator from right to left

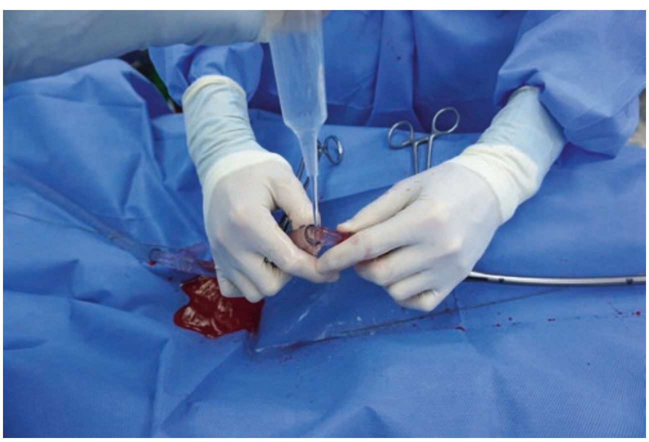


Fig. 11.9 An air-free connection under a continuous stream of saline is made between the circuit and the cannula

11.10 Cannula Selection

Drainage: 22 French multistage femoral venous cannula is adequate for most adults. For larger BSA (over 2.5 m^2), a 25 Fr. cannula may be necessary to ensure adequate drainage.

Return: A 19 or 21 Fr. single-stage femoral venous cannula can be used for return into the right atrium. It should be placed 5 cm deeper than the drainage cannula to decrease recirculation. A short arterial cannula can be used for return to the IJ vein, sized 17–20 Fr.

11.11 Special Considerations

- A double-lumen cannula can be placed through the right IJ vein into the IVC for VV ECMO. Transesophageal echocardiography and fluoroscopy are recommended for safe placement. A variety of sizes are available, with 27 or 31 Fr. used for most adults (Fig. 11.4).
- A double-lumen right ventricular assist device cannula is also available, with drainage from the RA and outflow into the PA.
- Prior to cannulation, ensure the proper cannulas are available as some cannulas depicted here are not routinely used in cardiac surgery.
- Anticoagulation protocols vary greatly by institution based on several factors, including coated circuits and pump design. Consultation with perfusion services is recommended.
- ECMO cannulas may traverse an IVC filter. Removal under fluoroscopy is recommended in this circumstance.

11.12 VV ECMO Removal

- Weaning from VV ECMO can be assessed by lowering the sweep gas to off while monitoring both oxygenation and ventilation. It is not necessary to decrease the flow as part of the weaning process.
- Percutaneous cannulas can generally be removed at the bedside.
- Purse-string sutures including the subcutaneous tissue are made around the cannulas.
- The ECMO circuit is clamped and the cannulas are removed. The sutures are tied, and manual pressure is held for hemostasis, often 15–30 min.

11.13 Venoarterial ECMO

- With the patient in supine position, both groins are widely prepped and draped.
- All necessary equipment is assembled (Fig. 11.5).
- Ultrasound guidance for vascular access is recommended (Fig. 11.6).
- For the drainage cannula, the common femoral vein (right, most commonly) is accessed with the introducer needle, and the cannula guidewire is then placed. Ectopy with wire placement is common and confirmatory of venous access.
- Common femoral arterial (CFA) access is obtained with the introducer needle followed by the guidewire. High access on the femoral artery is preferred, but not so high to complicate later femoral artery repair.
- Once both guidewires are placed, a bolus of anticoagulation can be administered.
- An incision large enough to accommodate the chosen cannula should be made along the tract of the wire.
- Careful serial dilation over the wire using the dilators included with the cannulas or a dilator kit should be performed. Great care should be taken to not bend the guidewire. Gentle tension should be maintained on the wire (Fig. 11.7).
- The sterile, primed tubing of the ECMO circuit should be brought onto the field and secured.
- Beginning with the drainage cannula, it should be advanced over the wire into proper position, usually 40 cm in an average adult. A twisting motion may be necessary to pass the cannula through the soft tissue of the groin (Fig. 11.8).
- The arterial cannula is advanced, but not to the point of dilating the artery with the wider portion of the cannula.
- The introducer and guidewire are pulled back swiftly, and the cannula is then clamped and deaired.
- An air-free connection under a continuous stream of saline is made between the circuit and the cannula (Fig. 11.9).
- The same steps should be taken for the return cannula.
- A purse-string suture incorporating the soft tissue incision should be used to secure the entry site of each cannula.
- Support can then be slowly initiated, watching for color change as the blood passes through the oxygenator. Sweep gas should be equal to flow and later adjusted based on arterial blood gas (Fig. 11.10).
- Additional sutures are placed along the length of the cannula to prevent dislodgement.
- Confirm proper cannula placement with CXR and/or KUB.

11.14 Cannula Selection

Venous: 22 Fr. multistage femoral venous cannula is adequate for most adults. For larger BSA (over 2.5 m^2), a 25 Fr. cannula may be necessary to ensure adequate drainage.

Arterial: A 15 Fr. femoral arterial cannula is adequate for most adults. For BSA over 2.2 m^2, a 17 Fr. cannula may be required to attain full flow.

11.15 Special Considerations

- At initiation of ECMO support, hypotension is common. This can be treated with volume administration, calcium chloride, or small doses of vasopressors.
- Outside of the operating room, percutaneous cannulation is preferred.
- If cannulating during CPR (E-CPR), accessing the right common femoral artery (CFA) and CFV minimizes complications.
- Arterial blood gases (ABGs) should be monitored from a right radial arterial line to minimize the risk of brain ischemia.
- Distal extremity perfusion should be assessed immediately following cannulation. Antegrade perfusion catheters should be placed as soon as ischemia is suspected or demonstrated. A variety of techniques are available to improve distal flow.
- Percutaneous vascular closure devices may be used before cannulation to simplify removal.
- Intra-aortic balloon pumps can be exchanged over an 0.018″ exchange-length guidewire. Percutaneous LVAD catheters (Impella™) are not able to be exchanged over a wire.
- Alternative access sites are possible, including central cannulation, axillary arterial cannulation, or drainage via the IJ vein.
- Prolonged cannulation may result in DVT from vascular injury or venous outflow obstruction.

11.16 VA ECMO Removal

- Cardiac recovery is assessed by decreasing the ECMO flow with the patient anticoagulated.
- An ejection fraction above 30% with no inotropic support is necessary to be successful.
- As flows are decreased with weaning, anticoagulation may be increased to prevent circuit thrombosis.
- FiO2 on the ventilator and the ECMO circuit is matched to assess for lung injury.
- If bedside evaluation determines the patient is able to wean, the patient should be scheduled urgently for decannulation in the operating room.
- An incision is made lateral to the arterial cannula. Proximal and distal control of the femoral artery is obtained (Fig. 11.11).

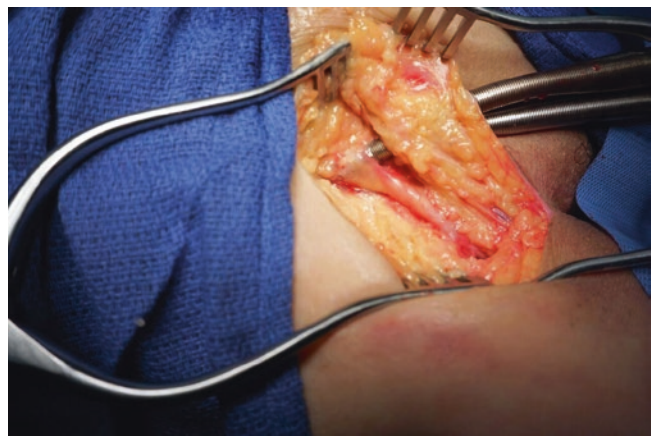


Fig. 11.11 The femoral artery is exposed through an incision lateral to the arterial cannula and carried in a curvilinear fashion cephalad

- A Prolene purse-string suture is placed around the venous cannula.
- The circuit is clamped and the artery is clamped distally, the arterial cannula is removed, and the proximal artery is clamped (Fig. 11.12).
- The femoral artery is then repaired. Distal flow is verified.
- The venous cannula is removed and the purse string is tied.
- The skin incision is closed in multiple layers.
- If concern for ongoing lung injury, be prepared to convert to VV ECMO.

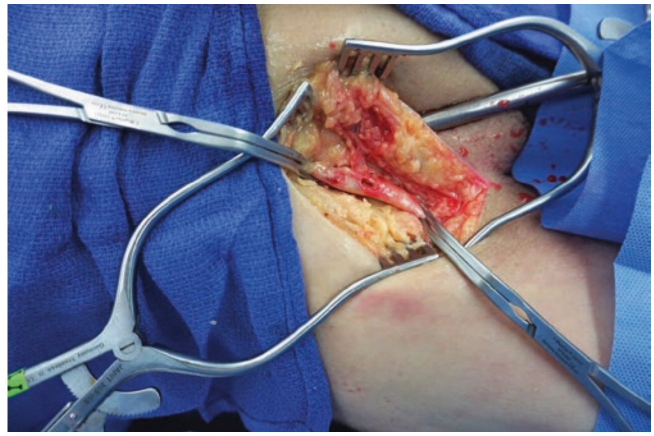


Fig. 11.12 Proximal and distal control is obtained on the femoral artery to allow for repair of the arteriotomy

Part III

Cardiovascular

12 Central Venous Catheters

James Bardes and Meghan Lewis

12.1 Surgical Anatomy

12.1.1 Internal Jugular Vein

- The internal jugular vein (IJ) courses deep to the sternocleidomastoid muscle, from the lobule of the ear to the medial end of the clavicle, where it joins the subclavian vein to form the innominate vein. It is lateral and superficial to the common carotid artery.
- Surface anatomic landmarks include the sternocleidomastoid muscle, its division into sternal and clavicular heads, as well as the clavicle, the external jugular vein, and the suprasternal notch (Fig. 12.1a, b).
- If an ultrasound probe is used for guidance, the internal jugular vein is identified as the lateral, compressible vessel in the neck. The carotid artery is located medially, and pulsation of the artery can be observed on ultrasound (Fig. 12.2a–c).

12.1.2 Subclavian Vein

- The subclavian vein (SC) is a continuation of the axillary vein, just below the middle of the clavicle. It joins the internal jugular vein to form the innominate vein.
- The subclavian vein is located anterior to the anterior scalene muscle, and the subclavian artery lies posterior to this muscle (Fig. 12.3a).
- Surface anatomic landmarks include the middle of clavicle and the sternal notch (Fig. 12.3b).

12.1.3 Femoral Vein

- The femoral vein is the continuation of the popliteal vein from the adductor canal to the inferior margin of the inguinal ligament, where it becomes the external iliac vein.
- The femoral vein lies medial to the femoral artery in the femoral sheath (Fig. 12.4a).
- Surface anatomic landmarks include the anterior superior iliac spine and the pubic tubercle. The inguinal ligament

J. Bardes · M. Lewis (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: James.bardes@med.usc.edu; meghan.lewis@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_12

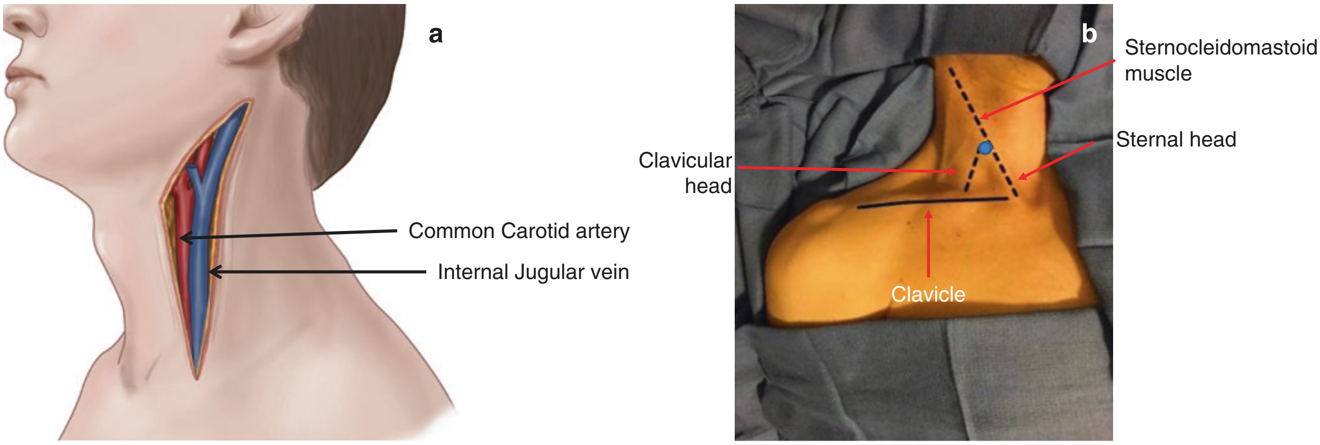


Fig. 12.1 (**a**) The IJ courses deep to the sternocleidomastoid muscle, lateral and superficial to the carotid artery. (**b**) Surface anatomy of the internal jugular vein: landmarks include the sternal and clavicular heads of the sternocleidomastoid muscle, the clavicle, and the suprasternal notch. The puncture site is at the apex of the division of the sternocleidomastoid muscle (*blue dot*) and advanced toward the ipsilateral nipple

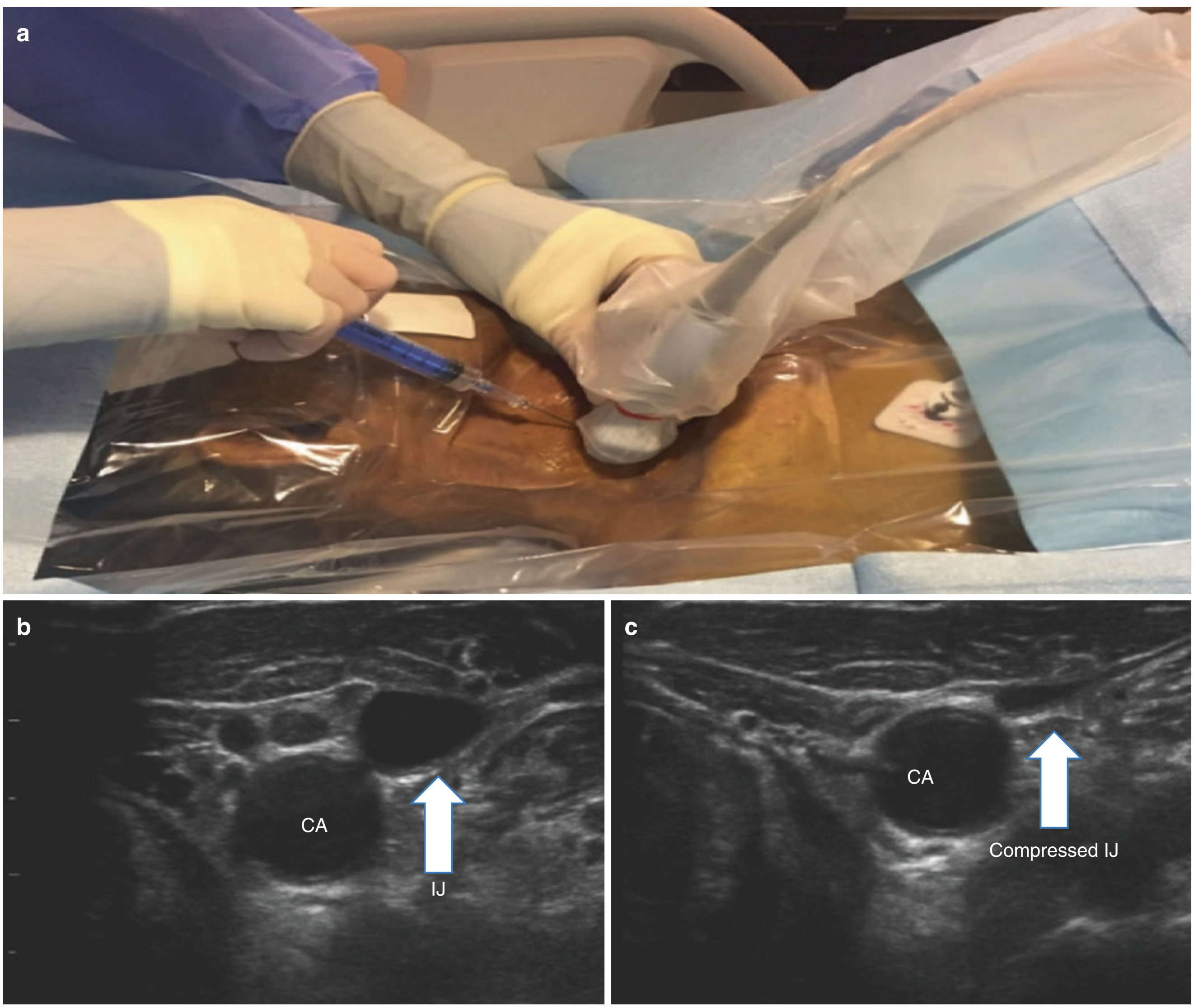


Fig. 12.2 The nondominant hand holds the ultrasound probe, while the dominant hand advances the Seldinger needle. Ultrasound demonstrates the internal jugular vein (*white arrow*) and carotid artery (CA) in short axis view. Note the dilated vein (**b**) which compresses easily (**c**)

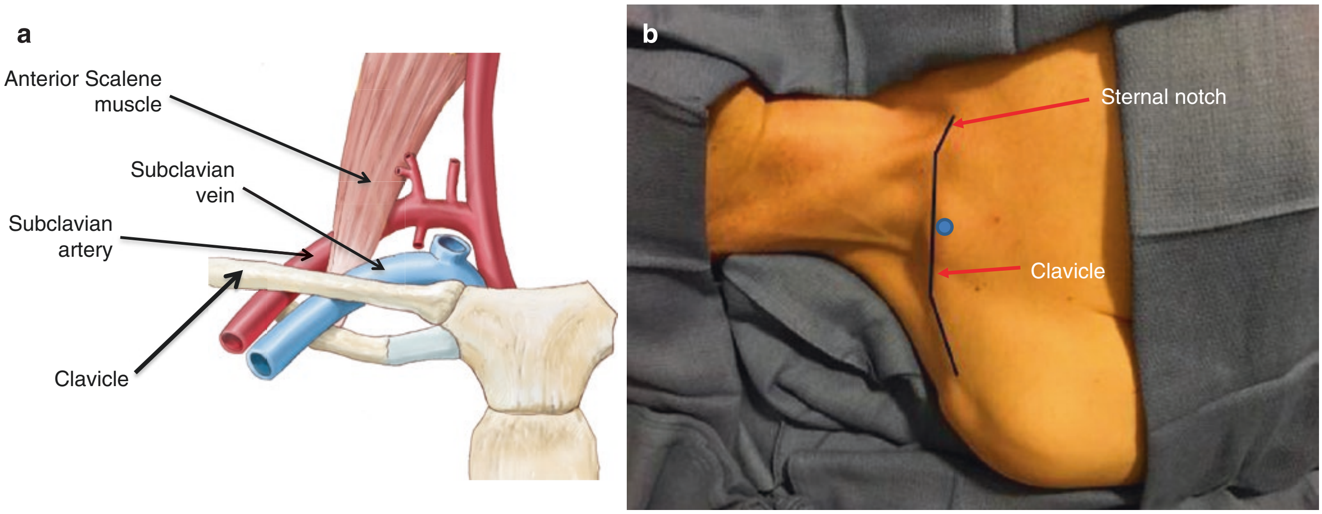


Fig. 12.3 (**a**) The subclavian vein is located anterior to the anterior scalene muscle, and the subclavian artery lies posterior to this muscle. (**b**) Surface anatomy of the subclavian vein. The venipuncture site is below the middle of the clavicle (blue dot), and the needle is aimed at the sternal notch

courses between these structures. The femoral sheath is contained in the femoral triangle, which is bound superiorly by the inguinal ligament (Fig. 12.4b).

- Ultrasound guidance may be used for improved accuracy when placing a femoral CVC. The vein is the compressible vessel located medially. The femoral artery is lateral, and the pulsation can be observed on ultrasound (Fig. 12.5a, b).

12.2 General Principles

- Indications for placement of a central venous catheter (CVC) include:
  - Vasopressor requirement
  - Specific medications that can only be administered centrally
  - Parenteral nutrition requirement

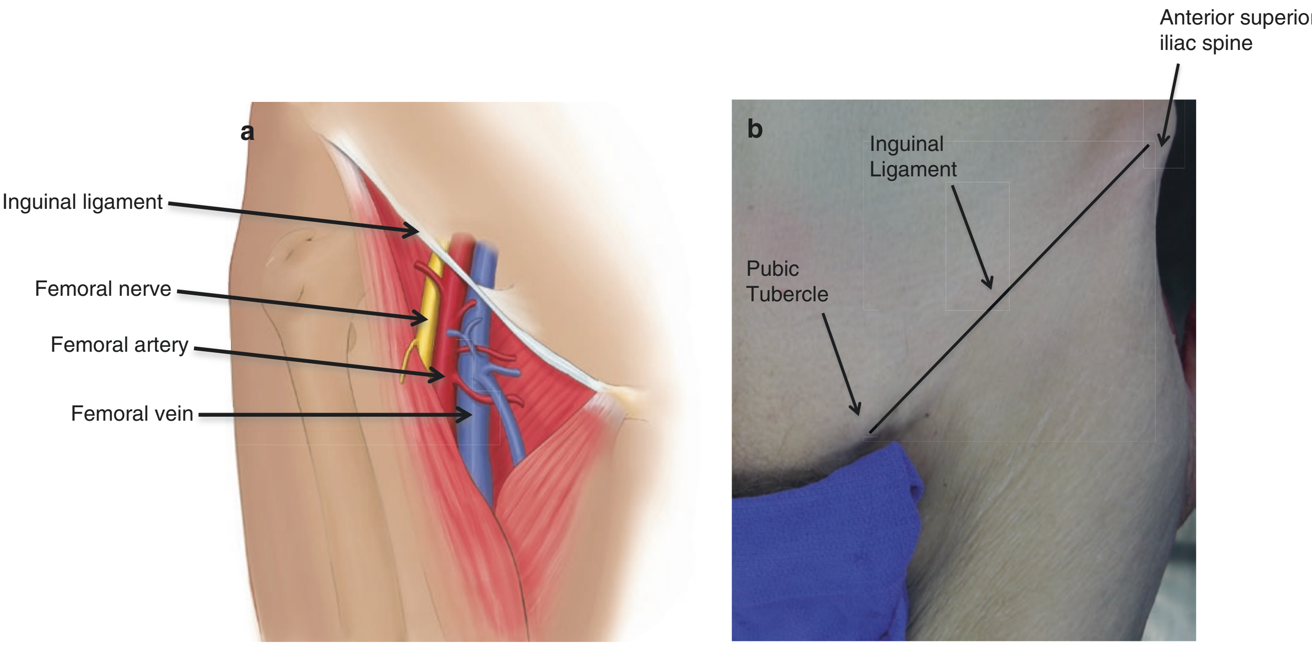


Fig. 12.4 (**a**) Anatomy of the femoral vein. The femoral vein lies medial to the femoral artery. (**b**) Surface anatomy of the femoral vein. Landmarks include the anterior superior iliac spine, the pubic tubercle, and the inguinal ligament

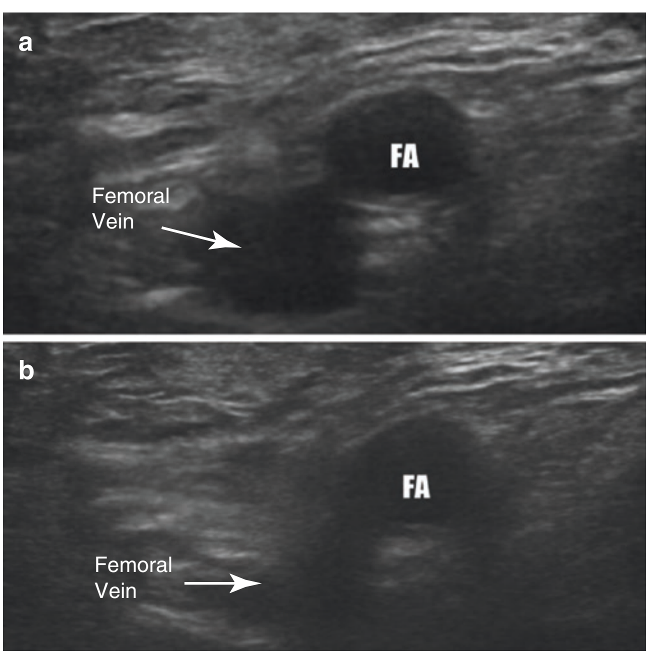


Fig. 12.5 (**a**) Ultrasound of the femoral vein (*white arrow*) and femoral artery (FA) in short axis view. (**b**) Vein demonstrated to be compressible

– Hemodynamic monitoring
– Placement of a pulmonary artery catheter
– Intravenous access in critically ill patients when peripheral access is unobtainable

- Consent from the patient or family member should be obtained whenever possible. Risks include:
  – Arterial puncture
  – Pneumothorax
  – Infection
  – Venous obstruction or thrombosis
  – Air embolus
- Elective procedures should be performed under full sterile precautions, including full-body draping, gown, mask, and sterile gloves. Skin disinfection with chlorhexidine is superior to alcohol or Betadine. The skin entry site should be covered with dry gauze or transparent breathable dressing. When ultrasound is used, the probe should be covered with a sterile probe cover.
- Catheters placed emergently, under suboptimal sterility, should be removed or replaced within 24 hours.
- IJ and SC sites are preferred due to lower rates of infection compared to femoral catheters.
- Ultrasound guidance should be considered the standard of care for internal jugular access and is highly recommended for femoral access when non-emergent.
- A chest X-ray should be obtained after IJ or SC catheter placement or after any attempts at placement. The chest X-ray has two purposes:
  – It assesses the position of the tip of the catheter. The tip should ideally be located at the junction of the superior vena cava and right atrium. This is approximately 3 cm below the right tracheobronchial angle.
  – It confirms there is no pneumothorax or hemothorax from needle puncture.

12.3 Instruments

- Multiple commercially available kits exist for CVC placement. The operator should ensure familiarity with the specific product prior to use.
- Antiseptic (chlorhexidine/silver sulfadiazine) or antibiotic-bonded (minocycline/rifampin) catheters should be considered if the duration of the catheter stay is expected to be >5 days.
- General contents of the kits include (Fig. 12.6):
  – 18 gauge needle for accessing the vein
  – 10 cc syringe
  – Guidewire
  – Scalpel
  – Dilator (sometimes multiple)
  – Catheter
- Additional equipment which may not be included in the kits:
  – Chlorhexidine prep
  – Sterile drapes, gloves, and gown
  – Local anesthetic
  – Appropriately sized needles
  – Additional syringes
  – Sterile saline
  – Chlorhexidine-impregnated sponge and sterile dressing
- Ultrasound equipment
  – High-frequency probe (greater than or equal to 7 MHz) for optimal resolution of superficial structures
  – Sterile probe cover

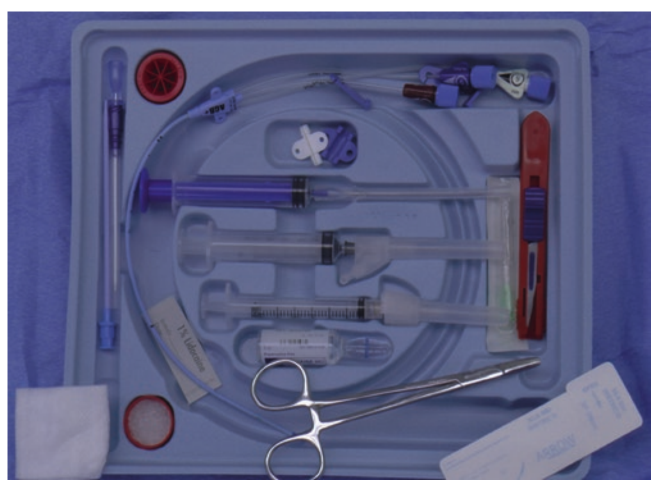


Fig. 12.6 Commercially available CVC kit

12.4 Positioning

12.4.1 Internal Jugular Vein

- The patient should be placed in the Trendelenburg position. This position dilates the IJ, as well as reduces the risk of air embolism.
- Ideal positioning involves turning the patient's head 45° to the contralateral shoulder. Alternatively, a neutral position can be used for patients requiring cervical spine precautions.
- Several approaches have been described; however, the use of ultrasonography is now considered standard of care. The landmark approaches should be reserved for situations in which ultrasound is not available.
  – Landmark approach (Fig. 12.7): The central approach is most common. In this approach, the skin is punctured at a 30° angle at the apex of the division of the sternocleidomastoid muscle and advanced toward the ipsilateral nipple.
  – Ultrasound-guided approach (Fig. 12.2): The vein is identified using two-dimensional sonography. The probe is held in the operator's nondominant hand and can be oriented to visualize the vein in the short axis, long axis, or oblique axis. The vein is distinguished from the artery by collapsibility. The skin is punctured at a 30–45° angle, and the needle is visualized in real time as it is advanced into the vein (Fig. 12.8).

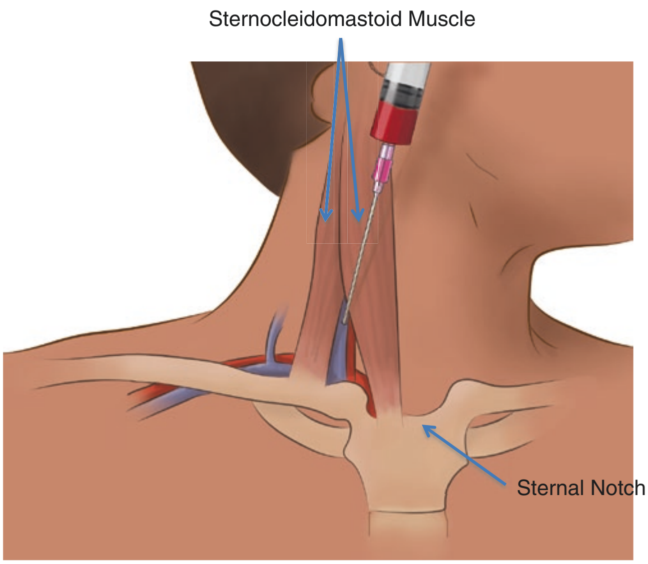


Fig. 12.7 Landmark approach to internal jugular venipuncture: the skin is punctured at a 30° angle at the apex of the division of the sternocleidomastoid muscle and advanced toward the ipsilateral nipple

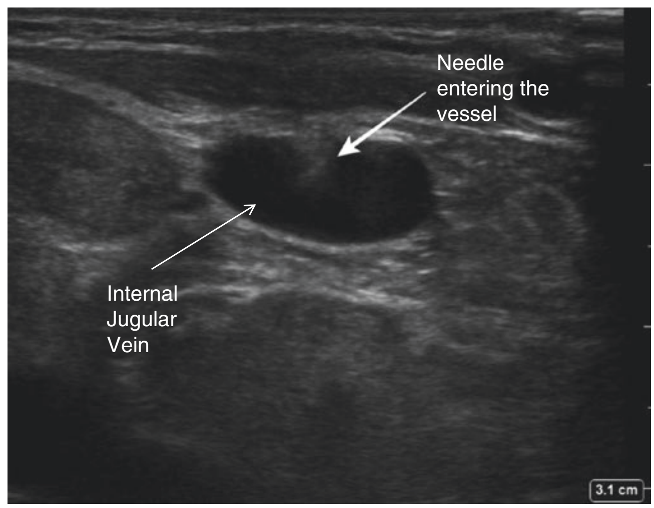


Fig. 12.8 Ultrasound short axis view visualizing the needle as it enters the vein in real time. The white arrow shows the tip of the needle entering the vein

12.4.2 Subclavian Vein

- The patient should be placed in Trendelenburg position to reduce the risk of air embolism.
- Ideal positioning involves a roll placed under the patient's shoulders. Alternatively, a neutral position can be used for patients requiring cervical spine precautions.
- The nondominant hand of the operator is placed over the clavicle, with the index finger in the sternal notch and the thumb at the angle of the clavicle in the deltopectoral groove (Fig. 12.9).
- The vein should be punctured as it crosses under the clavicle, at the lateral border of the medial 1/3 of the clavicle. The skin should therefore be punctured 1–2 cm inferior and lateral to this point.
- The needle is advanced inferior to the clavicle while aiming at the sternal notch.

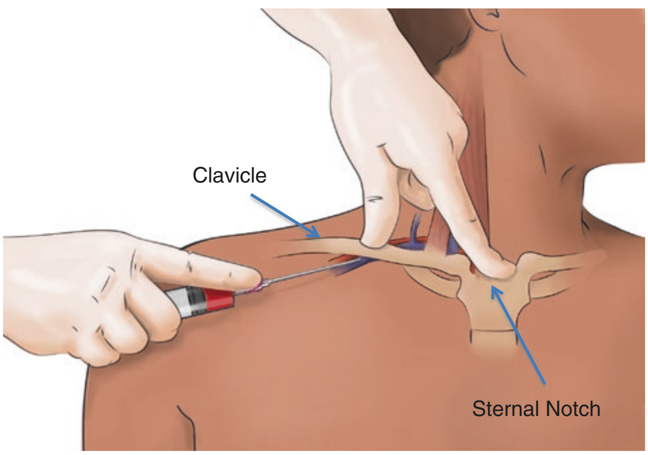


Fig. 12.9 Subclavian venipuncture: the insertion site is under the middle of the clavicle, and the needle is advanced inferior to the clavicle while aiming at the sternal notch

12.4.3 Femoral Vein

- The patient can be positioned supine or in reverse Trendelenburg. The leg can be abducted and externally rotated up to 15°.
- The vein should be punctured inferior to the inguinal ligament (Fig. 12.10).
- If there is a palpable pulse, the femoral vein can be found approximately 1 cm medial to it. Alternatively, ultrasound guidance can be used to identify the vein.

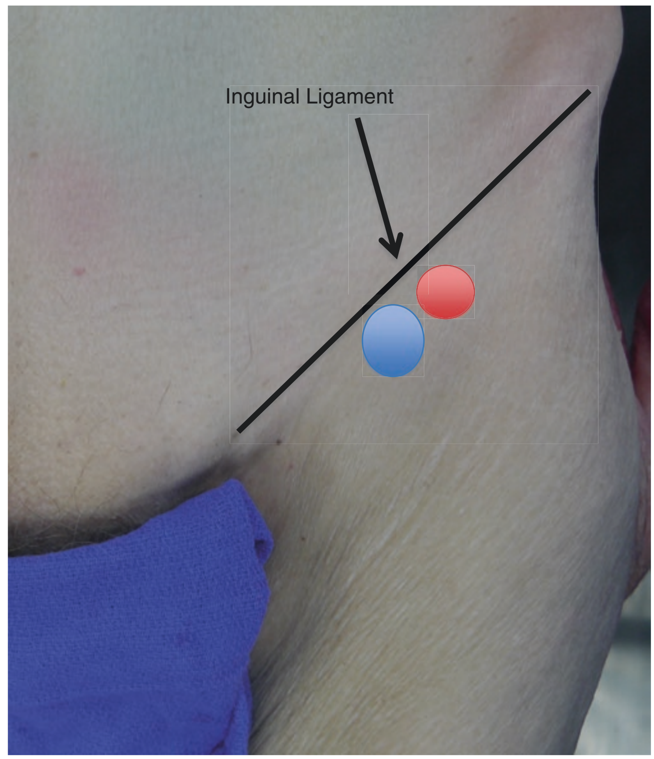


Fig. 12.10 Insertion site for femoral vein central line: the vein (*blue dot*) should be punctured inferior to the inguinal ligament, about 1 cm medial to the femoral pulse (*red dot*)

12.5 Technique

- The procedure should be performed under full sterile conditions, as described above, whenever possible.
- For IJ and SC sites, the distance between the intended cutaneous puncture site and the angle of Louis (manubriosternal junction) along the trajectory of the vein should be measured. This estimates the appropriate length of catheter to insert.
- The CVC and dilators should then be flushed with saline.
- Lidocaine is injected with a 25 gauge needle over the intended puncture site to provide local anesthesia.
- An 18 gauge Seldinger needle is used to access the desired vessel.
  – The operator should aspirate while advancing the needle. A rapid return of blood indicates venipuncture. Venous blood should be dark and non-pulsatile (Fig. 12.11a, b).
  – Advancing the needle can oppose the anterior and posterior walls of the vessel, collapsing the lumen and permitting the needle to pass through both walls of the vessel. For this reason, if no return of blood is obtained after appropriate depth of needle advancement, the needle should be withdrawn slowly with continued aspiration.
- Once the vein has been accessed, the needle is stabilized in position with the nondominant hand, while the syringe is removed from the needle.
- The J-tip of the guidewire is then inserted through the Seldinger needle into the vessel (Fig. 12.12). The wire should be advanced approximately 15–20 cm. The operator will then maintain the guidewire with the nondominant hand throughout the remainder of the procedure.
- The needle should be removed.
- If performing an ultrasound-guided IJ or femoral catheter, the ultrasound can be used again to confirm placement in the vein (Fig. 12.13).
- A #11 blade is then used to make a 5 mm stab incision adjacent to the guidewire, but avoiding the wire itself. There should be no skin bridge between the guide wire and the stab incision (Fig. 12.14).
- A dilator should then be advanced with the operator's dominant hand over the wire and into the vessel. The end of the guide wire is maintained by the nondominant hand while advancing the dilator (Fig. 12.15). The dilator should not be advanced more than a few millimeters into the vein (this distance can be estimated based on the depth that was required for venipuncture).
  – Between advances of the dilator, the wire should be advanced and retracted slightly within the dilator to confirm that no false passage has been created with the dilator.
  – The dilator is then removed, and slight pressure should be applied to the insertion site to prevent excessive blood loss.
  – If the line requires more than one dilator, they are used successively, from smallest to largest.
- The CVC is then advanced over the guidewire to the predetermined adequate depth (Fig. 12.16):
  – Right IJ—advance to approximately 15 cm
  – Right SC—advance to approximately 16 cm
  – Left IJ—advance to approximately 17 cm
  – Left SC—advance to approximately 18 cm
  – Femoral—advance to hub
- The guidewire should then be removed from the catheter (Fig. 12.17).
- A trace of blood should be drawn from each port with subsequent flushing of sterile saline to confirm function and to clear the line.
- The catheter is then secured to the skin with simple nonabsorbable sutures (Fig. 12.18).
- Lastly, a sterile dressing is applied.
- A portable chest X-ray should be ordered after placement of an IJ or SC catheter (Fig. 12.19).

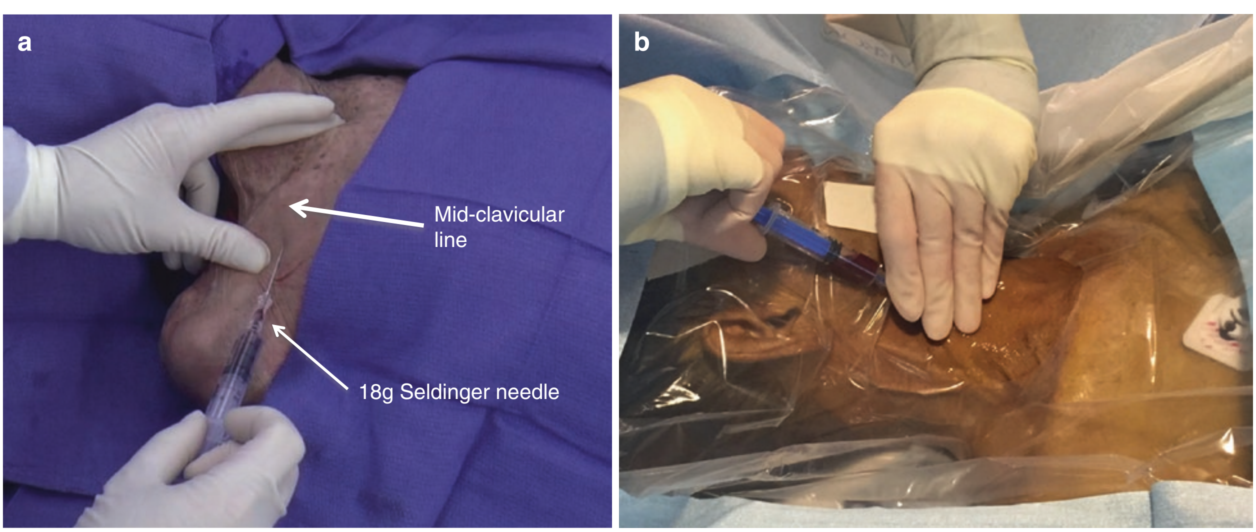


Fig. 12.11 (**a**) An 18ga Seldinger needle is used to access the selected vein, and venous blood is aspirated. (**b**) After venipuncture, the syringe is removed from the needle

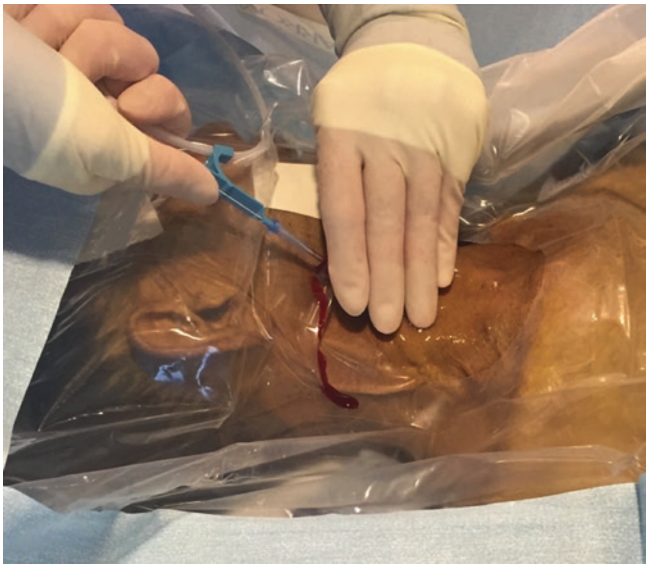


Fig. 12.12 The guidewire is advanced through the Seldinger needle. The nondominant hand is used steady to the needle

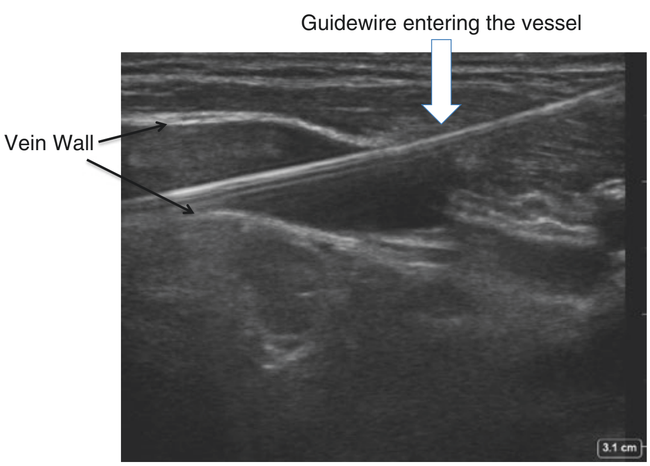


Fig. 12.13 Ultrasound long-axis view confirms the wire is located within the vein (*white arrow*)

Fig. 12.14 A #11 blade is used to make a small stab incision adjacent to the guidewire

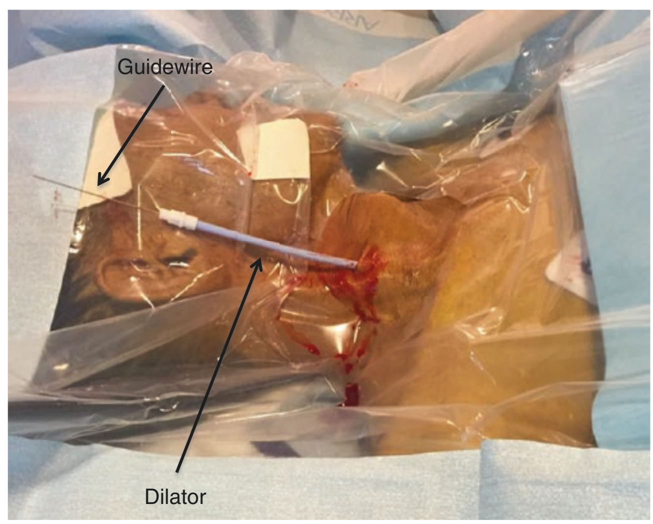


Fig. 12.15 A dilator is advanced over the guidewire. Note: the operator's hands have been removed for an unobstructed view. The operator should maintain the end of the wire with the nondominant hand at all times

Fig. 12.16 The catheter is advanced over the guidewire to the desired length, while the free end of the wire is grasped with the nondominant hand

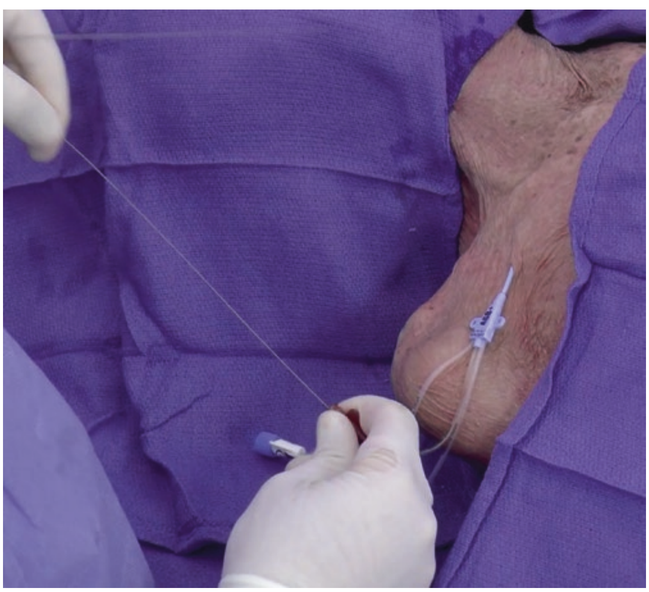


Fig. 12.17 The guidewire is removed from the catheter

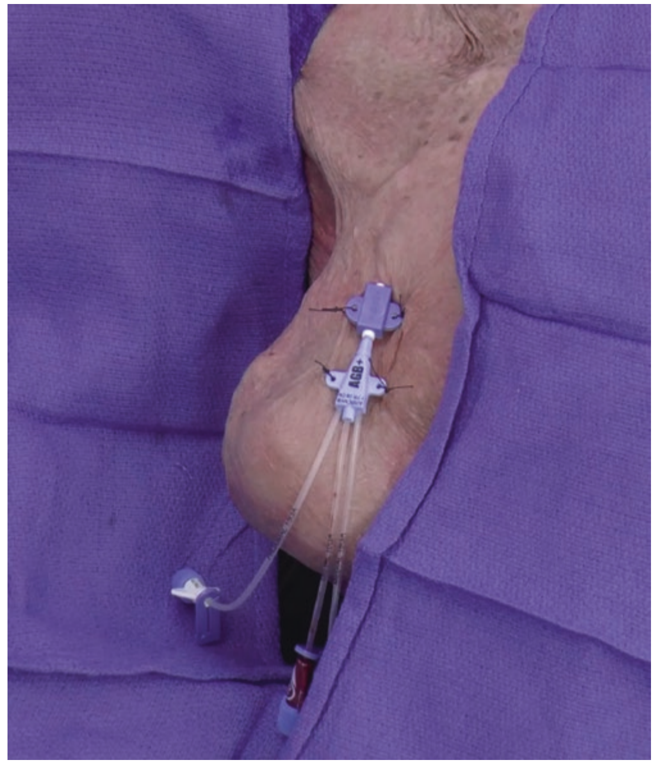


Fig. 12.18 The catheter is sutured in place

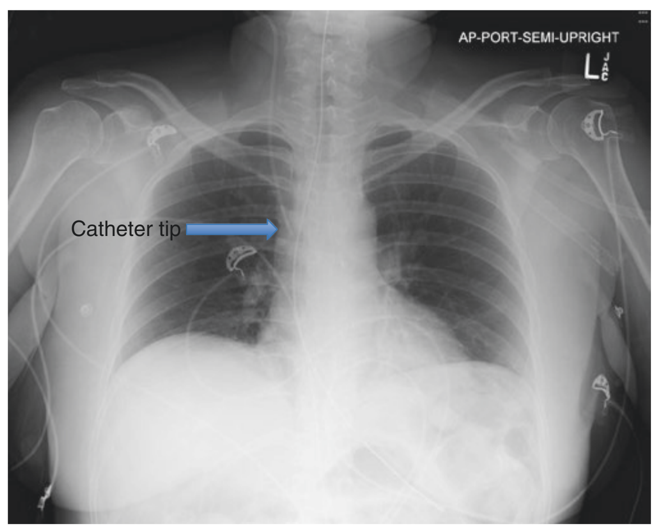


Fig. 12.19 Chest X-ray is used to confirm placement of the catheter. The catheter tip should be at the junction of the SVC and right atrium (*arrow*)

12.6 Removal

- Catheters should be evaluated daily for medical necessity.
- To remove internal jugular or subclavian lines, the patient should be placed in Trendelenburg position, which decreases the risk of air embolism.
- The sterile dressing is removed, the sutures are cut, and the catheter is slowly retracted while applying pressure over the vein.
- Pressure should be held on the site for 10 min, and then hemostasis should be confirmed. If the patient is coagulopathic, pressure may need to be held for up to 30 min.
- A sterile dressing can then be applied.

12.7 Tips and Pitfalls

- Patients should be on telemetry during placement. If any ectopy occurs on the monitor, the wire should be withdrawn until it ceases. Arrhythmias after catheter placement indicate catheter tip irritation of the right atrial wall (the catheter has been advanced too far).
- The femoral vein should not be punctured above the inguinal ligament, as this is the external iliac vein. This is a non-compressible vessel, which increases the likelihood of a retroperitoneal hematoma after puncture or after line removal.
- If an arterial puncture occurs with the Seldinger needle, simple pressure can be held. However, if the dilator or catheter has been advanced into an artery, then placement of the line should be completed, and it should be connected to a pressure bag. Surgical or interventional arterial repair will be required.
- For subclavian or IJ central lines, the tip of the catheter should be in the superior vena cava. Placement of the catheter in the right atrium risks cardiac perforation and tamponade.

13 Techniques of Intraosseous Access

James Bardes and Aaron Strumwasser

13.1 Surgical Anatomy

- Intraosseous (IO) infusion is based on the principle that medullary veins of long bones remain patent during shock and hypovolemia.
- IO infusion sites include the humerus, proximal tibia, distal femur, and manubrium.

13.2 General Principles

- IO infusion is an alternative mode of achieving vascular access in the injured or critically ill patient (adult or pediatric). It is indicated in acute, life-threatening situations when standard venous access cannot be achieved.
- IO access may be an acceptable first attempt venous access in patients in full cardiopulmonary arrest or severe shock. In these cases, IO cannulation and peripheral venous access may be attempted simultaneously.
- The success rates of IO placement with the battery-powered device are higher than 95%. With the battery-operated device, access is normally achieved in less than 1 min.
- Intraosseous access provides a route for all advanced cardiac life support (ACLS) fluids and drugs, at the same doses prescribed for traditional intravenous access. However, adenosine, antibiotics, and phenytoin require adjusted dosing for IO administration. The IO cannula should be flushed before and after administration of any medication.
- IO cannulation allows fluid or blood products resuscitation and administration of medications. Peripheral blood sampling can be performed via IO cannulation.
- In critically ill patients in cardiac arrest or severe shock, IO placement is performed without local anesthesia. However, in awake patients, local anesthesia at the insertion site is recommended. Infiltrate the soft tissues and the periosteum with 1% lidocaine.
- The fluid and blood infusion rate is equivalent to a 21 gauge intravenous catheter (150–160 mL/h). Resuscitation fluids should be administered under pressure, using an infusion pump and pressure bag or manually.
- Intraosseous catheters should be replaced with a venous line as soon as possible, but some series have reported up to 72 hours of safe use. In general, catheters that stay in place beyond 24 hours are associated with increased risk of osteomyelitis.
- The IO site should be monitored frequently for infiltration.
- IO placement is contraindicated in the presence of extremity fracture, severe local soft tissue trauma, proximal venous injury, or any infection at the site chosen. Patients with right-to-left intracardiac shunts may be at risk for cerebral fat embolism.

13.3 Equipment/Types of Intraosseous Catheters

- Intraosseous catheters come in a variety of forms. The basic types include (1) manual needles, (2) battery-powered driver, and (3) impact-driven devices.
- The choice of device (manual, battery-powered, or impact-driven) is based on patient age and physician preference.
  - In infants under 1 year of age, consider manual needles or battery-powered devices.
  - In children 1 year of age or older, adolescents, and adults, consider a battery-powered device.
- Optimal needle size depends on the age of the patient. Commercially available IO kits contain needles that are color-coded according to age.

J. Bardes · A. Strumwasser (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: James.bardes@med.usc.edu; Aaron.strumwasser@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_13

13.4 Anatomical Sites and Patient Preparation

13.4.1 Proximal Tibia

- The patient should be supine with the knee slightly flexed if possible.
- Assistants stabilize the lower leg manually and the knee supported by towel rolls.
- The tibial tuberosity is palpated just below the knee.
- The insertion site is then chosen two fingerbreadths (2 cm) distal to the tibial tuberosity and slightly medial on the flat portion of the tibia (Fig. 13.1).

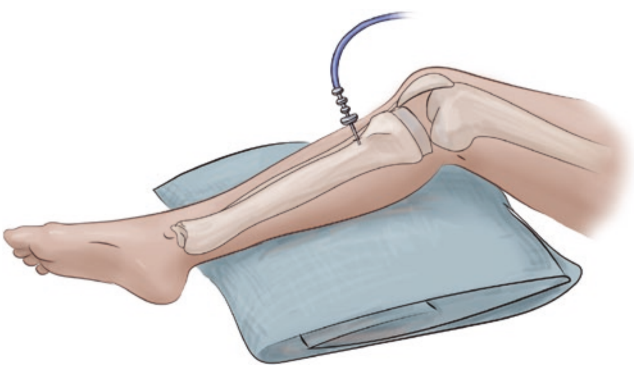


Fig. 13.1 Anatomy of the proximal tibia. The insertion site is about 2 cm distal and just medial to the tibial tuberosity

13.4.2 Sternum

- Ensure that the IO device chosen is intended for sternal placement.
- Patients are positioned supine.
- The sternal notch is palpated and a site selected for insertion 2 cm distal, within the manubrium. Some manufacturers provide a device-specific guide for sternal placement (target patch) to assist with site identification and cannulation (Fig. 13.2).

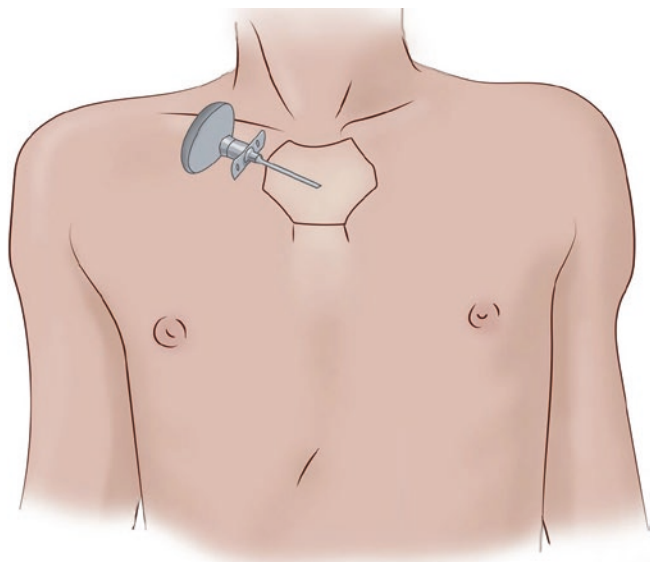


Fig. 13.2 Sternal anatomy. The insertion site is about 2 cm distal to the sternal notch, within the manubrium

13.4.3 Humerus

- The patients should be supine, with the elbow adducted and arm internally rotated across the torso. When positioned correctly, the palm overlies the umbilicus. This will minimize the likelihood of brachial plexus injury.
- The humerus is then palpated, and the greater tuberosity is identified as the insertion point, approximately 2 cm below the acromion process (Fig. 13.3).
- This should be used only in skeletally mature adolescents and adults, ideally cannulated using battery-powered or spring-loaded impact devices.

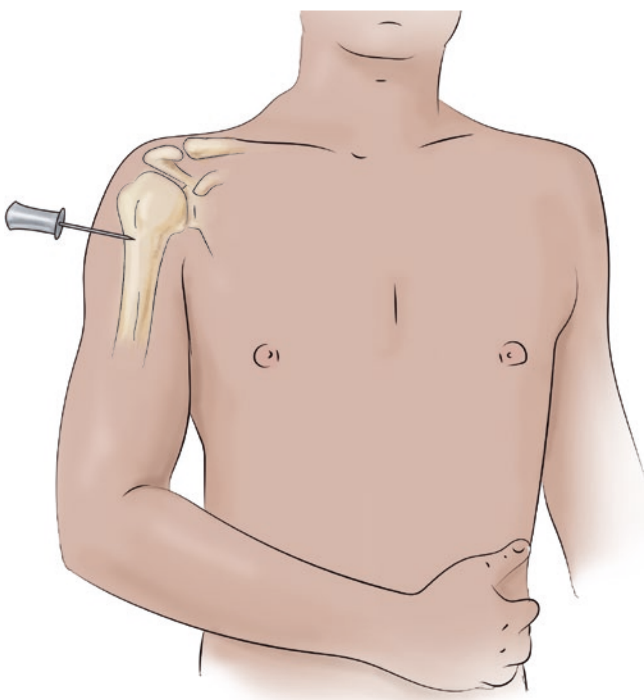


Fig. 13.3 Humerus insertion site. The greater tuberosity is identified, about 2–3 cm inferior to the acromion process

13.4.4 Distal Femur

- This site is less commonly chosen due to difficulty in palpating the bony landmarks in most patients.
- The patients hip should be slightly flexed and externally rotated; the knee should also be slightly flexed.
- The insertion site is 2–3 cm above the superior border of the patella with the leg in extension. The device is inserted in the anterior midline at this level (Fig. 13.4).

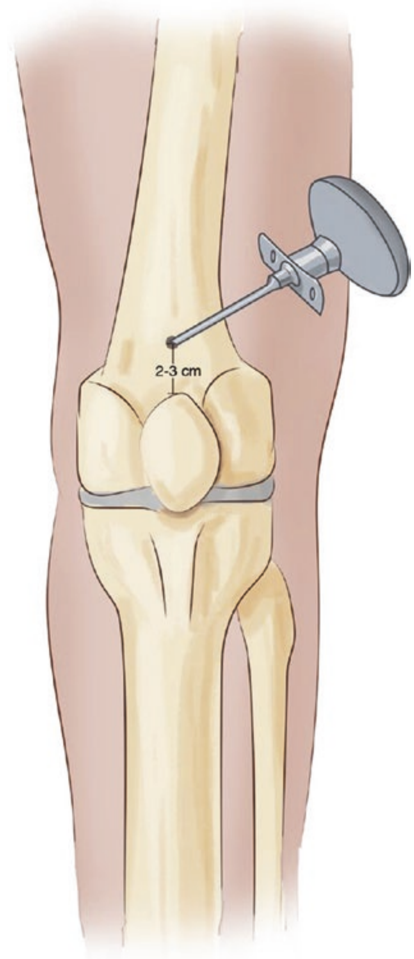


Fig. 13.4 Distal femur insertion site. The patella is palpated, and a midline site selected 2–3 cm proximally

13.5 Tibial Intraosseous Catheterization Procedure

13.5.1 Battery-Powered Driver (Fig. 13.5)

- Position the patient as described above.
- Prep the insertion site with chlorhexidine.
- In the awake patient, inject 3–5 cc of 1% plain lidocaine at the insertion site and adjacent to the periosteum.
- Check the equipment, needle size, and battery.
- Remove the safety cap, and position the needle perpendicular to the bone (Fig. 13.6).
- Squeeze the trigger, and use light driving pressure to penetrate bone, ensuring a minimum of 5 mm of catheter remains above the skin. If there is difficulty penetrating the bone, making a small skin incision may help with skin penetration of the needle (Fig. 13.7).
- When there is a loss of resistance, release the trigger, wait for the driver to stop spinning, and then unscrew the needle stylet, rotating it counterclockwise (Fig. 13.8).
- Connect IV tubing and aspirate marrow to confirm correct placement (Fig. 13.9).
- Flush with 10 mL of saline, and apply a sterile dressing.
- To remove the needle, grasp the shaft and pull up with a rotary motion away from the bone. Apply a sterile dressing (Fig. 13.10).

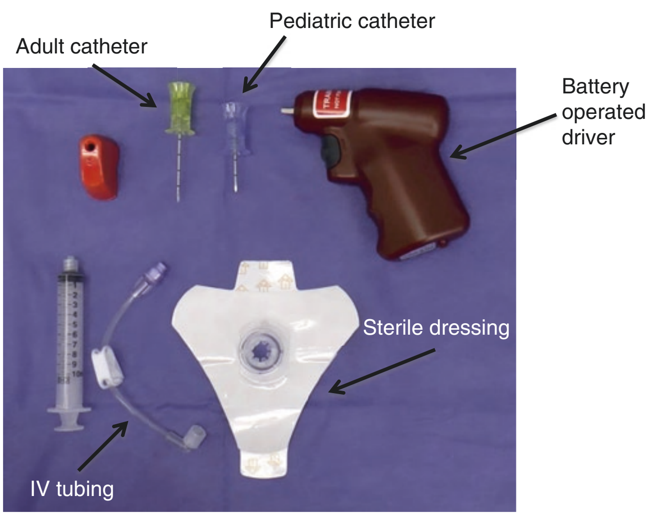


Fig. 13.5 Battery-operated driver kit and components

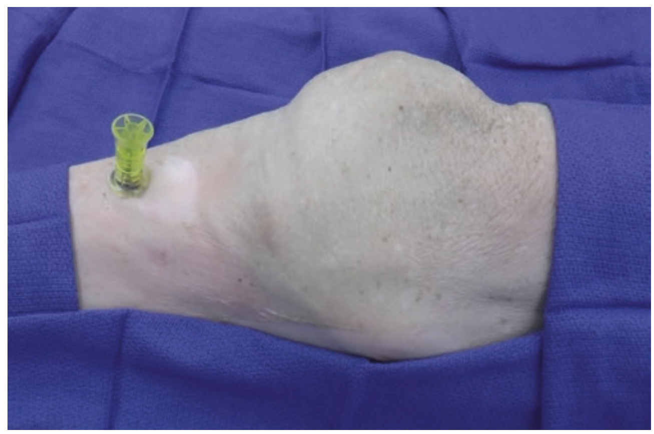


Fig. 13.7 The needle is advanced into the bone with 5 mm of catheter left above the skin

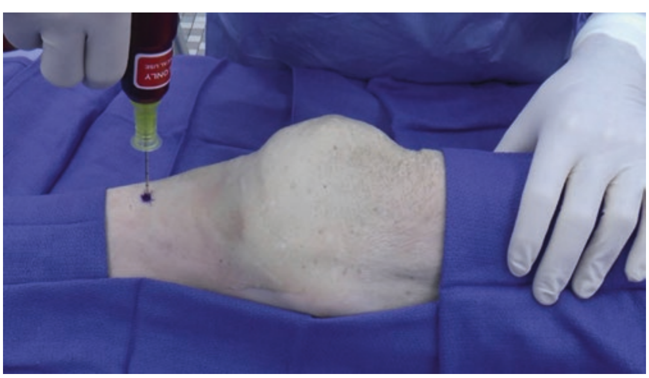


Fig. 13.6 Position the needle perpendicular to the bone, and squeeze the trigger of the battery-operated driver

Fig. 13.8 Remove the inner stylet (white arrow) from the catheter

Fig. 13.9 IV tubing is connected to the catheter and marrow is aspirated

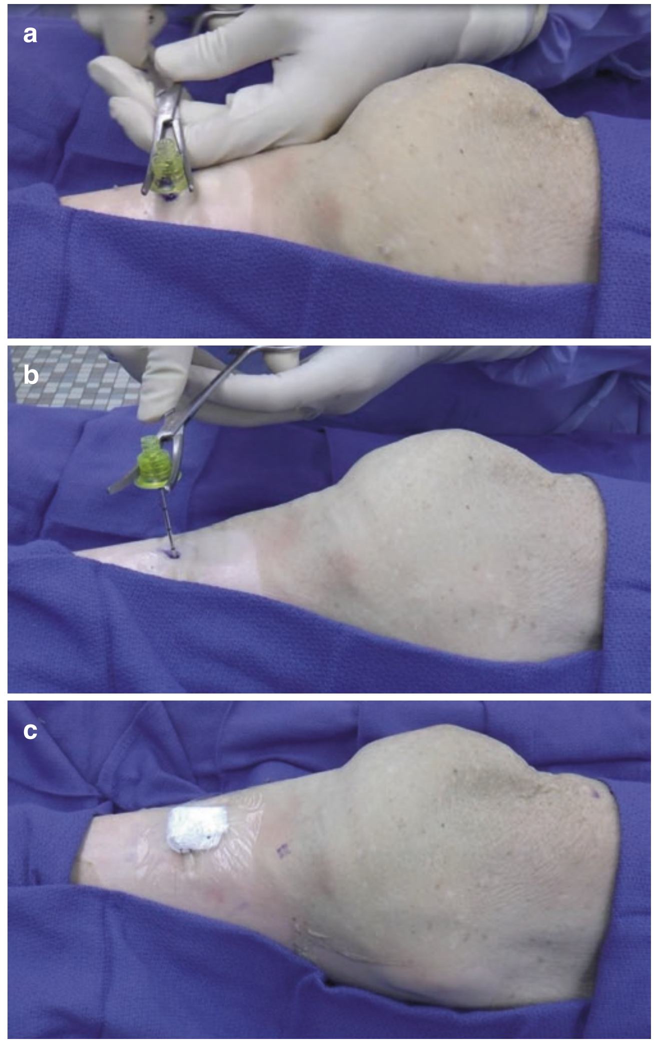


Fig. 13.10 For removal, (**a**) the catheter is grasped (**b**) and pulled up in a rotary motion. (**c**) A sterile dressing is applied

13.5.2 Manual Needle

- Position the patient, and prepare the insertion site with chlorhexidine and local anesthetic as described above.
- Select an appropriately sized device (Fig. 13.11).
- Apply a twisting motion, directing the IO needle perpendicular and slightly away from the knee joint (10 degrees from perpendicular) (Fig. 13.12).
- When the needle penetrates through the cortex of bone into the marrow, a sudden "give" or unimpeded resistance is felt (Fig. 13.13).
- Unscrew the needle cap and remove the inner cannula. Confirm correct needle placement by aspiration of marrow.
- Once placement is confirmed, flush the catheter with 10 mL of saline, and apply a sterile dressing.
- Follow the similar procedure above to remove the catheter.

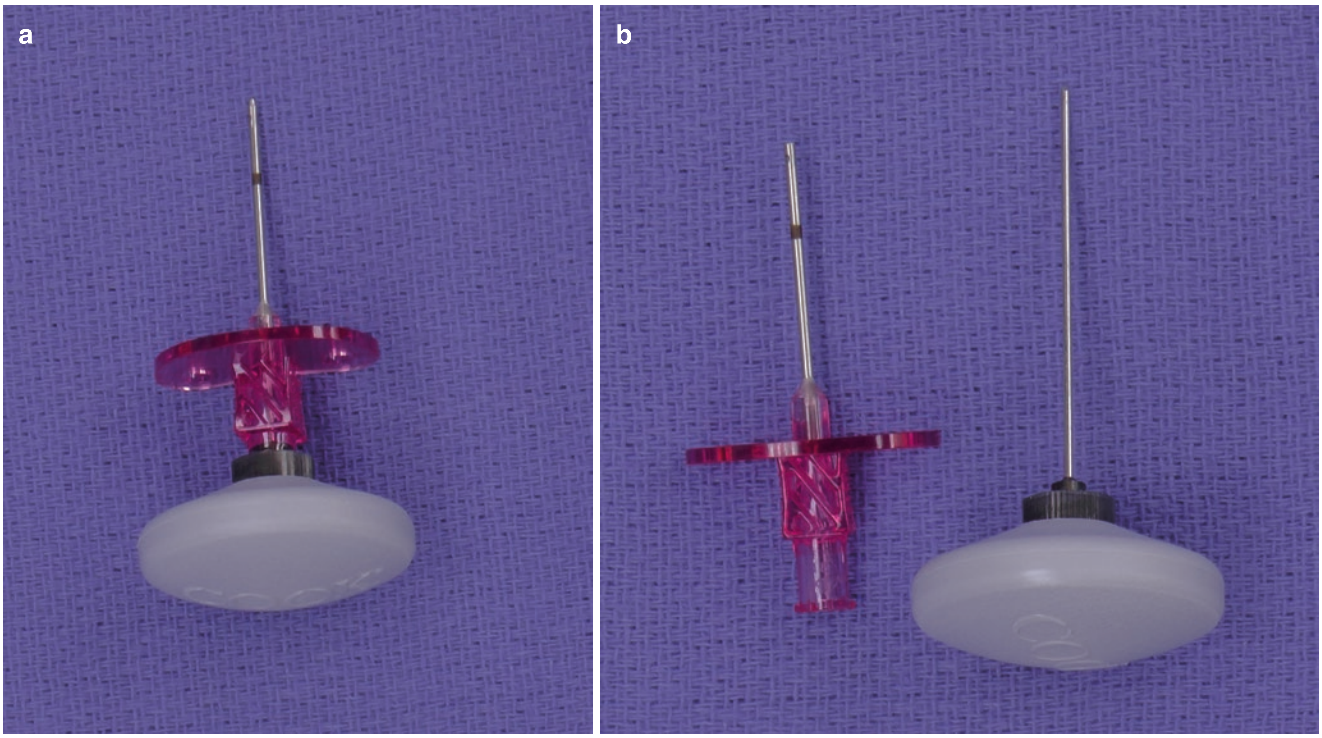


Fig. 13.11 (**a**) Manual needle ready for insertion. (**b**) Manual needle with inner cannula removed

Fig. 13.12 A twisting motion directs the manual needle into the cortex

Fig. 13.13 Manual needle inserted in the proximal tibia

13.6 SterNal Intraosseous Catheterization Procedure

13.6.1 Impact-Driven Device

- Position the patient and select the insertion site as described above.
- Use the target patch to center the needle appropriately; the adhesive pad is placed adjacent to the sternal notch to maintain alignment. Ensure that the "target zone" resides centrally over the manubrium.
- Remove the sharps plug and introducer, confirm alignment of the target patch, and place bone probe needles into the target zone (Fig. 13.14).
- Apply pressure to the introducer in perpendicular fashion until a "pop" is heard and the handle separates from the device.
- Remove the introducer and blue cap from the IO catheter and connect the infusion tubing.
- Aspirate bone marrow, flush with 10 mL of normal saline, and apply a sterile dressing.
- For removal, while holding the target patch, carefully peel away the protector dome, disconnect the tubing, and pull the tube including the metal tip up and away from the chest. Apply sterile dressing.

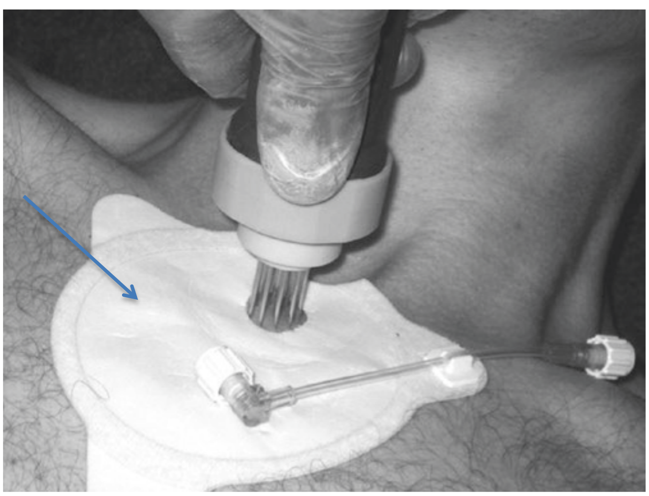


Fig. 13.14 A target patch (*blue arrow*) correctly aligns a sternal IO device over the manubrium

13.7 Complications

- Intraosseous cannulation is considered to be relatively safe, with a rate of serious complications of less than 1%.
- Complications include needle displacement, compartment syndrome, skin necrosis, osteomyelitis, subcutaneous abscess, and tibial fracture. Fat embolism is a very rare complication (Figs. 13.15 and 13.16).
- Osteomyelitis may occur when an IO needle remains in place for 24 h or longer.
- Intraosseous catheters do not interfere with bone growth.
- Sternal IO cannulation with inappropriately long needle may result in injury to the mediastinal vessels or the heart.

Fig. 13.15 Incorrectly placed IO catheter can cause extravasation, leading to compartment syndrome in some cases. This X-ray demonstrates the catheter tip (*Black arrow*) is through the posterior surface of the bone

Fig. 13.16 Infection of the intraosseous insertion site

13.8 Tips and Pitfalls

- A battery-powered device is preferable in both pediatric and adult patients.
- A correctly placed IO catheter (1) stands firmly on its own within the bone, (2) aspirates bone marrow, and (3) flushes without evidence of extravasation (remember that resistance is expected because the marrow cavity does not distend). Even if marrow does not aspirate easily, if there is no sign of extravasation, the IO can still be used.
- A wrong size needle can cause serious injury and complications. Choose the size of the needle carefully, based on the age of the patient.
- If extravasation occurs with an IO, evaluate and monitor for compartment syndrome.

Pulmonary Artery Catheter Placement

14

Subarna Biswas, Katharina Pellegrin, and Bradley Allen

14.1 General Principles

Although the routine use of the pulmonary artery catheter (PAC), also referred to as a Swan-Ganz catheter (Fig. 14.1), has fallen out of favor, they can be valuable in directing therapy in select patients. The most common indications for PAC placement are the evaluation and/or management of patients with complicated myocardial infarction, unexplained or unknown volume status in shock, severe cardiogenic shock, and suspected or known pulmonary arterial hypertension (PAH). PACs may be placed perioperatively in patients undergoing open-heart surgery or with congenital heart disease, severe valvular disease, left-to-right shunt, and severe underlying cardiopulmonary disease.

- Consent from the patient or family member should be obtained whenever possible. Risks include arterial puncture, bleeding, cardiac arrhythmias, pneumothorax, infection, venous thrombosis, air embolism, cardiac perforation, cardiac tamponade, pulmonary embolism, and pulmonary hemorrhage.
- Measurements of the following can be obtained from a pulmonary artery catheter (PAC):

Directly measured	Derived measurements
Central venous pressure (CVP)	Systemic vascular resistance (SVR = 80 × [mean artery pressure − CVP]/CO)
Right-sided intracardiac pressures (right atrium, right ventricle)	Pulmonary vascular resistance (PVR = 80 × [mean PAp − PAOP]/CO)
Pulmonary arterial pressure (PAP)	Cardiac index (CI = CO/body surface area)
Pulmonary artery occlusion pressure (PAOP) also known as pulmonary capillary wedge pressure (PCWP) which reflects left atrial pressure	Stroke volume index (SVI = CI/heart rate)
Cardiac output (CO)	Left ventricular stroke work index (LVSWI = [mean systemic artery pressure − PAOP] × SVI × 0.136)
Mixed venous oxyhemoglobin saturation (SvO_2)	Right ventricular stroke work index (RVSWI = [mean PAp − CVP] × SVI × 0.136)
	Oxygen delivery (DO_2 = CI × 13.4 × hemoglobin concentration × arterial oxygen saturation)
	Oxygen uptake (VO_2 = CI × 13.4 × hemoglobin concentration × [arterial oxygen saturation − Venous oxygen saturation])

- Waveform analysis (right atrial and PCWP) allows assessment of tricuspid and mitral valve function (regurgitation or stenosis) as well as cardiac tamponade.
- Blood oxygen sampling in the right atrium, RV, and pulmonary artery can document intracardiac shunts.
- The mixed venous oxygenation level (MVO2) is determined by blood taken from the pulmonary artery (distal port of PAC) as it is where blood has mixed from the SVC, IVC, and coronary sinus. MVO2 allows one to determine the adequacy of cardiac output.
- Cardiac output determined by thermodilution (most common method with PAC) is well validated but can be incorrect in the case of tricuspid regurgitation (underestimate CO) or intracardiac shunts (overestimate CO).
- A PAC allows infusions of medications directly into the heart (right atrium, right ventricle, pulmonary artery), and some enable cardiac pacing.

S. Biswas (✉) · K. Pellegrin · B. Allen
University of Southern California, Los Angeles, CA, USA

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_14

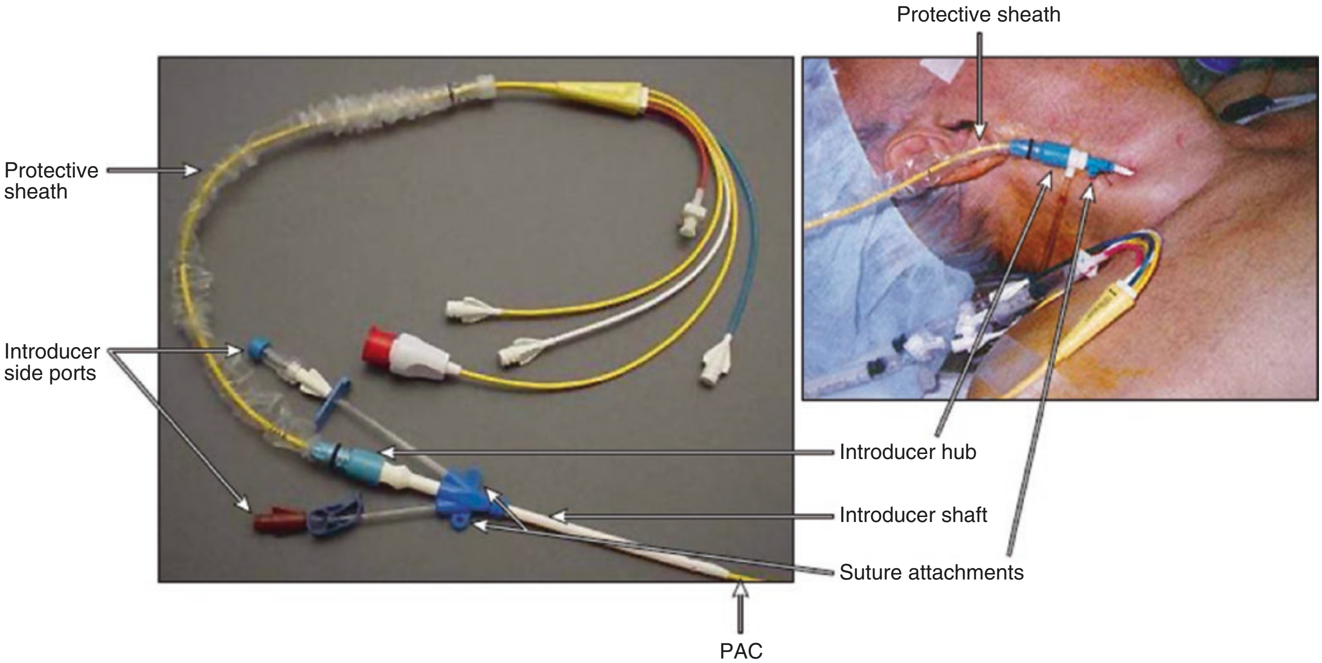


Fig. 14.1 Pulmonary artery catheters are placed through introducer sheaths in the internal jugular or subclavian veins. They have at least four ports: a distal port which is used to transduce pressures; a balloon inflation port; a thermistor port, used to monitor patient temperature and obtain cardiac outputs; and the right atrial or CVP port

Absolute contraindications for insertion are:

- Right-sided endocarditis
- Right atrial thrombus or mass
- Tricuspid valve mechanical prosthesis
- Right ventricular assist device

Relative contraindications include:

- Left bundle-branch block (as rarely the PAC can cause right heart block when traversing the right ventricle thereby leading to complete heart block)
- Severe coagulopathy
- Infection at insertion site
- Hypothermia

14.2 Patient Preparation and Positioning

- Knowledge of cardiac anatomy and intracardiac pressure waveform analysis are key to success of placing a PAC.
- The site of insertion should be selected in advance so that the appropriate equipment can be in place. The right internal jugular and left subclavian veins are preferred because the curvature of the PAC facilitates passage from these sites into the pulmonary artery. If those sites are unavailable, the right subclavian vein is usually preferable to the left internal jugular vein.
- Femoral cannulation should be generally be avoided except in the patient who is anticoagulated or undergoing thrombolysis where bleeding is a concern. Femoral insertion is more difficult in the absence of fluoroscopy and carries a higher VTE and infection risk.

14.2.1 Equipment

- Multiple commercially available PAC kits exist. The operator should ensure familiarity with the specific product prior to use. The usual PAC is 110 cm long and 5–8 French in diameter. It is marked with a thick line to denote 50 cm and thin lines every 10 cm and has 2–5 lumens (2–3 lumens most common). All PACs have at least four ports: the distal port which is used to transduce pressures during insertion; the balloon inflation port, used to inflate and deflate the distal balloon; the thermistor port, used to monitor patient temperature and obtain cardiac outputs; and the right atrial or CVP port (located at the 30 cm mark). In most PACs, there is a fifth port (3rd lumen) which can be used for IV infusions or occasionally for pacing (Fig. 14.2).
- General contents of a PAC kit include:
  18 gauge needle for accessing the vein
  10 cc syringe
  Guidewire
  Scalpel
  Dilator (sometimes multiple)
  Catheter introducer
  Pulmonary artery catheter
  3 cc syringe for distal PAC balloon
  Catheter plastic sterile sleeve
  Drapes
- Other equipment
  Mask, cap, sterile gown, sterile gloves, and sterile drapes
  Portable ultrasound with vascular probe
  Electrocardiographic (ECG) machine/cardiac monitor
  Chlorhexidine solution/swab
  Ampule 1% lidocaine
  At least two three-way stopcocks
  Saline flushes
  Suture
  Sterile dressings including Tegaderm and Biopatch
  Electronic pressure monitor to display waveforms during insertion

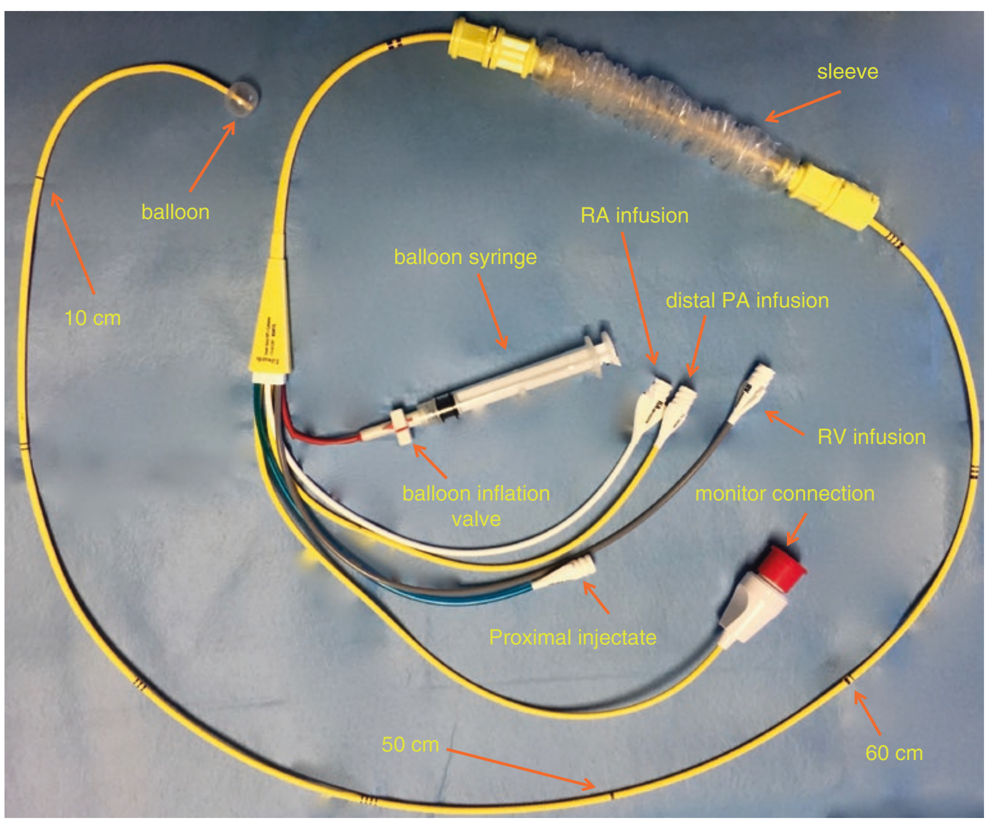


Fig. 14.2 Pulmonary artery catheter with sleeve and balloon syringe. The catheter is 110 cm long and marked with thick lines every 50 cm and thin lines denoting 10 cm. All catheters have ports terminating in the right atrium, right ventricle, and pulmonary artery. Test the balloon by inflating and deflating it through the locking pink port with the included syringe

14.2.2 Technique

In most instances, the introducer sheath is placed just prior to introducing the PAC, but a previously placed introducer sheath (Cordis) can also be used. Once the site has been selected, place the patient in a supine position, and unless using a femoral vein approach, turn the head slightly away from the site of the sheath.

14.2.2.1 Preparation

- A circulating assistant, typically the patient's bedside nurse, must be available to help with manipulating the unsterile parts, such as connecting the PAC ports to the monitor, adjusting the monitor, and, when requested, inflating/deflating the distal balloon.
- The operator must have an unobstructed view of the monitor during insertion to assess the pressure waveforms.
- Full antiseptic precautions (wash hands with antiseptic solution and don sterile garments and sterile gloves).
- Apply sterile prep and drape.
- As described in central venous cannulation chapter, perform ultrasound-guided venous cannulation of desired location, place guidewire through needle, advance Cordis catheter over wire using Seldinger technique, and remove the dilator.
- Slide the pulmonary artery catheter through its plastic sleeve, ensuring that the sleeve connector is facing the distal end of the catheter. Inflate and delate the balloon to confirm that there are no air leaks after sliding the PAC through the sleeve. Use only the syringe that is supplied with the catheter, since it will fill only to the balloon's capacity. To minimize the risk of mechanical trauma during insertion, the inflated balloon should completely encircle the catheter tip. Hand the end of the catheter and compressed sleeve off of the sterile field to the assistant.
- Have the assistant connect all PAC lumens to stopcocks, and flush each with sterile saline to eliminate any air in the catheter lumens.
- Attach the distal port of the PAC to the main pressure monitor. The proximal infusion port may also be connected for CVP monitoring. Place the catheter tip level with the patient's heart, estimated as the fourth intercostal space in the midaxillary line with the patient in the supine position. Set the monitor pressure to zero at this level. Flick the PAC tip to check frequency response. This ensures the monitor is connected and working properly as the pressure waveforms displayed on the monitor will be needed during insertion.
- Once zeroed, the monitoring system must be calibrated for accuracy. Most monitors perform an automated electronic calibration. To manually calibrate, raise the distal tip of the PAC to a specified height above the heart, and set the monitor pressure appropriately. For example, raising the tip 20 cm above the left atrium (midaxillary line) should produce a reading of approximately 15 mm Hg if the system is working properly.
- Monitor pressures continuously from the distal PAC lumen. We usually use a 0–60 mmHg view on the monitor screen to appreciate the change in pressure tracings during catheter advancement. The monitor must be continuously observed during insertion for changes in waveform as the PAC is advanced through the introducer. The PAC will travel through the superior vena cava (SVC), right atrium (RA), right ventricle (RV), and pulmonary artery, while the pressure at its distal tip is transduced. The pulmonary capillary wedge pressure is usually obtained at approximately 45–55 cm.

14.2.2.2 Procedure

- Orient the catheter so that its intrinsic curvature follows the expected path through the heart to optimize the probability of passing through the tricuspid valve and into the right ventricle (Fig. 14.3).
- Next, place the PAC through the introducer sheath and maximally inflate the balloon once it has passed through the introducer, approximately at the 15–20 cm mark on the catheter. The balloon should not be inflated inside the introducer.
- Advance the catheter until a right atrial pressure waveform (Fig. 14.4a, b) is transduced. The distance to the right atrium is typically 20 cm from an internal jugular or subclavian vein and approximately 40–50 cm from a femoral vein. Normal right atrial pressure is 0–6 mmHg. From this step onward, the balloon should be inflated whenever the catheter is advanced and deflated whenever the catheter is withdrawn.
- Advance the catheter another 5–10 cm until a right ventricular pressure waveform is transduced (Fig. 14.5a, b). This waveform contains a swift upstroke and downstroke, representing ventricular systole and diastole. Normal systolic pressures in the RV range from 15 to 30 mmHg, while diastolic pressure is from 0 to 6 mmHg, the same as right atrial pressure as the tricuspid valve is open during diastole. If the RV waveform is not seen by the time the PAC is at the 30–35 cm mark (60–70 cm if inserted from the femoral vein), the balloon should be deflated and the catheter withdrawn back to 15–20 cm (and start the advancement a second time), as it has most likely passed through the RA without traversing the tricuspid valve.
- The risk of arrhythmias is greatest while the PAC tip is in the RV, so the catheter should be advanced from RV to PA without delay.
- Continue to advance the catheter through the RV another 5–10 cm until a pulmonary artery pressure waveform is transduced (Fig. 14.6a, b). This waveform also contains a systolic pressure waveform, but it is distinguished from the right ventricular waveform by an overall increase in diastolic pressure and a dicrotic notch (representing closure of the pulmonic valve). Normal systolic pressure in the PA remains 15–30 mmHg, while diastolic pressure normally varies from 5 to 12 mmHg.
- If you reach the 40–50 cm mark on the catheter and you still don't see the PA tracing (assuming IJ or subclavian insertion site), then the catheter is probably coiling in the

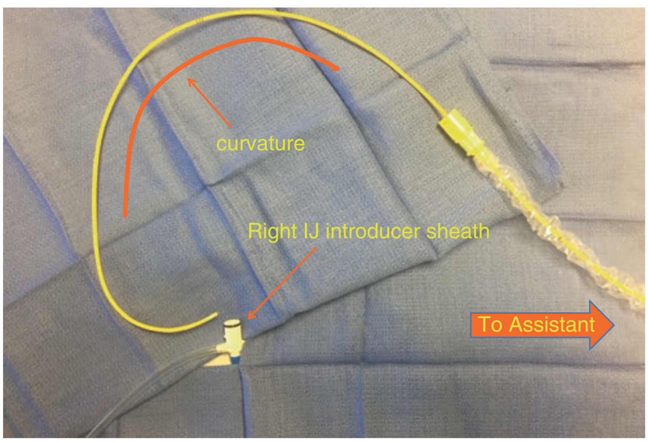


Fig. 14.3 Pulmonary artery catheter just prior to insertion through right internal jugular introducer sheath. All hubs and balloon inflation syringe should be handed off the sterile field to the assistant

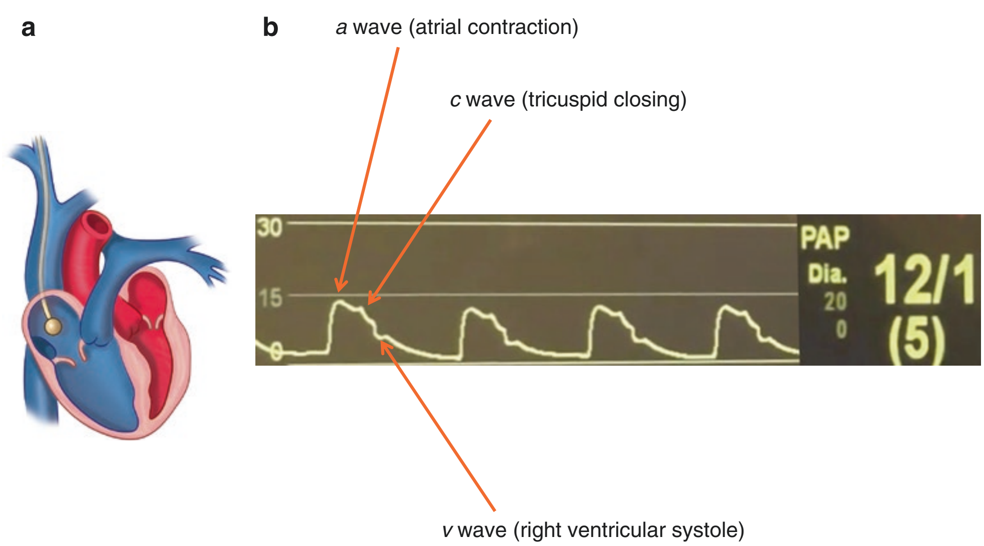


Fig. 14.4 (**a**) Pulmonary artery catheter in the right atrium, balloon inflated. (**b**) The right atrial waveform has several identifiable components: an *a* wave, which indicates atrial contraction; an *x* descent, which indicates atrial relaxation; a small *c* wave, which indicates closure of the tricuspid valve; a *v* wave, which indicates passive atrial filling during right ventricular systole; and a *y* descent, which indicates passive atrial emptying following the opening of the tricuspid valve. The distance to the right atrium is typically 15–20 cm from an internal jugular or subclavian vein and approximately 40–50 cm from a femoral vein

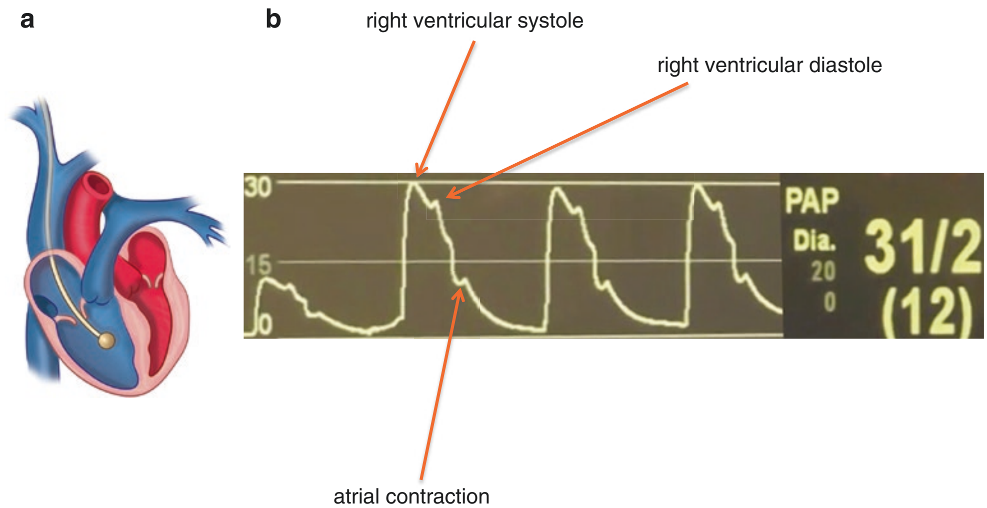


Fig. 14.5 (**a**) Pulmonary artery catheter in the right ventricle, balloon inflated. (**b**) The right ventricular waveform contains a swift upstroke and downstroke, representing ventricular systole, and a slower upstroke, representing passive ventricular filling during diastole followed by right atrial contraction

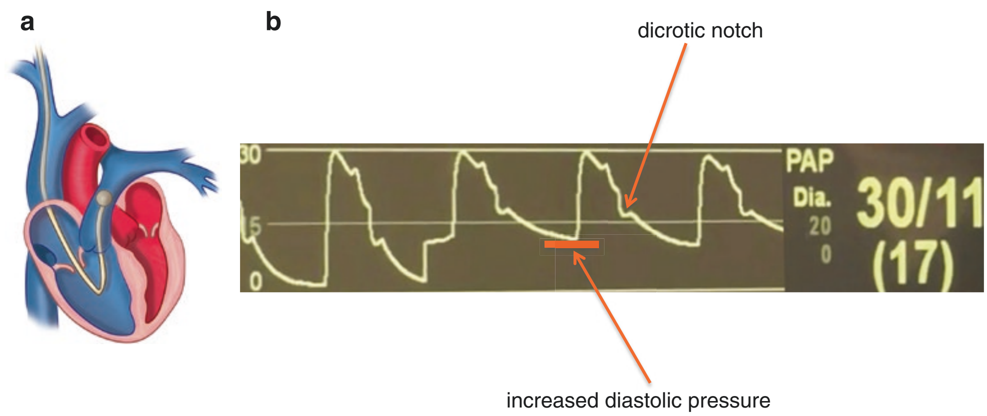


Fig. 14.6 (**a**) Pulmonary artery catheter entering the pulmonary artery, balloon inflated. (**b**) The pulmonary artery waveform is distinguished from the right ventricular waveform by an overall increase in diastolic pressure and a dicrotic notch (representing closure of the pulmonic valve)

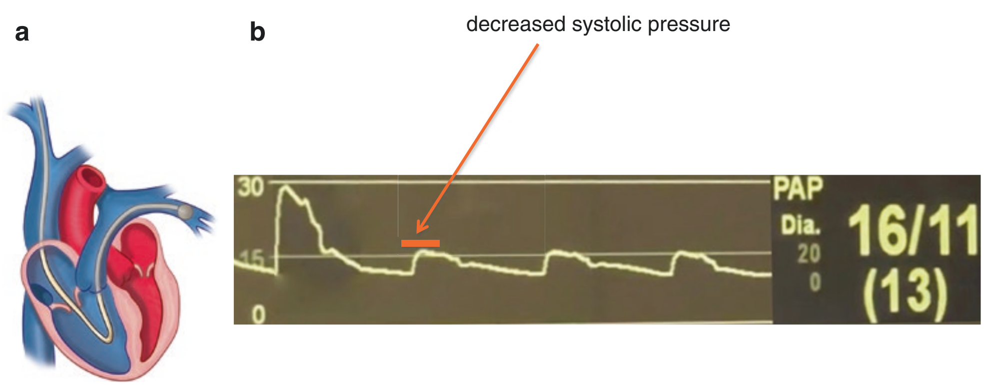


Fig. 14.7 (**a**) Pulmonary artery catheter wedged, balloon inflated. Balloon should be deflated once the PAC is in the correct position. (**b**) The pulmonary capillary wedge pressure waveform is similar to the right atrial waveform and is recognized by an overall dampening of the pulmonary artery waveform. This generally occurs when the catheter has been inserted 40–50 cm from the internal jugular or subclavian vein and 60–70 cm from a femoral vein

RV, or the RV is very large. In this case deflate the balloon and withdraw it back to the RA (20 cm mark). If persistent coiling occurs, the patient can be repositioned in the left lateral position with the head titled slightly upward to encourage floatation into the PA. Owing to gravitational pressures and anatomic features, most catheters float to the right PA. Thus to catheterize the left PA selectively, the patient should be positioned with the right side down.

- Advance the catheter further until the waveform indicating pulmonary capillary wedge pressure is transduced (Fig. 14.7a, b). This waveform is similar to the right atrial waveform (since it represents left atrial pressure), except

that greater variation may be noted during respiration. Normal wedge pressures range from 2 to 12 mmHg.

- Once insertion is complete, deflate the balloon and confirm the reappearance of a pulmonary artery pressure waveform. If this waveform does not reappear, slowly withdraw the catheter with the balloon deflated until it does. Then confirm that the PCWP is obtained by inflating the balloon slowly.
- The final position of the catheter within the PA must be such that a PCWP is obtained whenever 75–100% of the 1.5 maximum volume of the balloon is insufflated. If less than 1 cc of air is required, the catheter is in a distal PA and should be withdrawn, as further inflation may lead to vessel rupture. If maximal balloon inflation fails to result in a PCWP, the catheter is too proximal and needs to be advanced.
- Note the final position of the catheter. Confirm that the balloon has deflated. Fasten the plastic sleeve to the sheath, which will secure the catheter and may reduce the risk of infection (Fig. 14.8). Verify that the sheath is sutured to the skin, and apply adhesive dressing.

14.2.2.3 Complications

- Arterial puncture
- Cardiac arrhythmias
- Air embolism
- Pneumothorax
- Venous thrombosis
- Cardiac perforation and tamponade
- Pulmonary embolism
- Pulmonary hemorrhage
- Infection

14.2.2.4 Aftercare

- Obtain a portable chest radiograph to evaluate the position of the catheter and to rule out a pneumothorax. To minimize the risk of pulmonary perforation or infarction, make sure that the catheter tip does not extend more than 4–5 cm beyond the midline (Fig. 14.9).
- The balloon can be periodically reinflated to reassess PCWP but should always be deflated afterward. The wedge should always be measured at end expiration, when pressures within the chest are equal to atmospheric pressure.

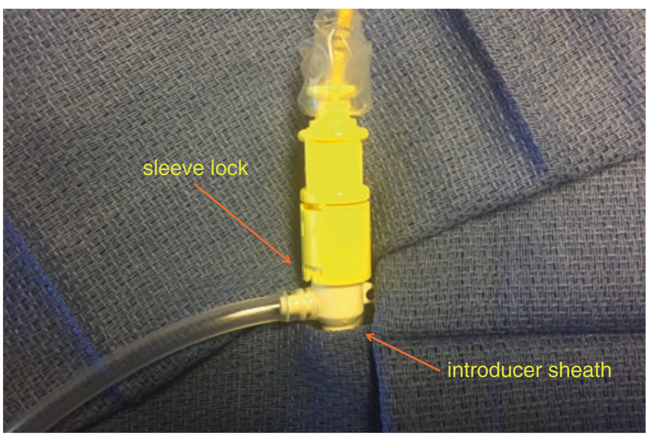


Fig. 14.8 Fasten the plastic sleeve to the sheath, and lock the catheter in place by turning the locking mechanism on the sleeve. The plastic sleeve allows for sterile repositioning of the catheter in the future without full barrier precautions

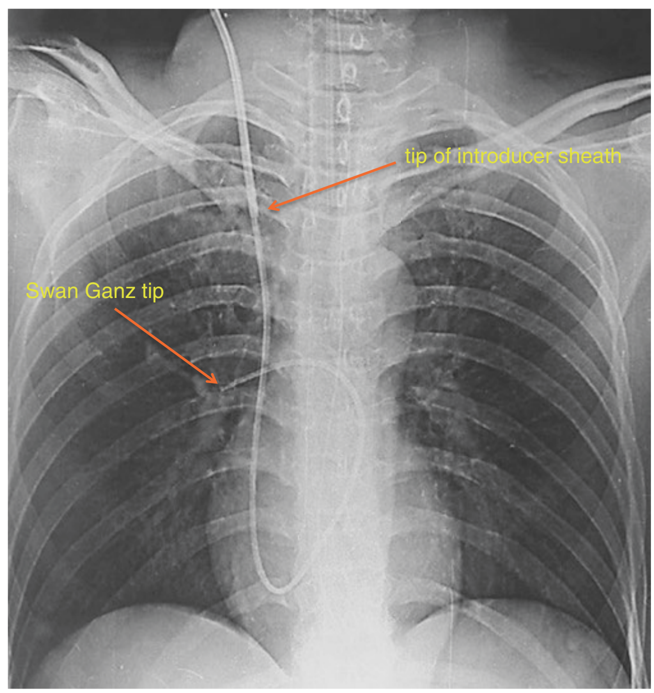


Fig. 14.9 Obtain a chest X-ray after PAC placement. The tip of the Swan should not extend more than 5 cm beyond midline

14.3 Tips and Pitfalls

- Make sure the balloon is fully inflated whenever the PAC is advanced and fully deflated whenever it is withdrawn.
- Resuscitation equipment should be available as arrhythmias and vascular complications can occur during insertion.
- CVP and PCWP pressures should be measured at end expiration to negate the effects of intrathoracic pressure. In the past this required measuring the pressure on the actual waveform. However many ICU monitors today measure pressure in 4 s time intervals and display systolic, diastolic, and mean pressure. The PCWP and CVP can be serially followed and measured at the end of expiration on these monitors by using systolic (peak) for those patients breathing spontaneously (with positive pressure at end expiration) and diastolic pressure (trough) for patients receiving positive-pressure ventilation (most patients with a PAC). This approach avoids false depression or elevation of intravascular pressure measurements due to fluctuations in pressure during respiration.
- PAC-pressure readings are most accurate when the pulmonary capillary pressure exceeds the mean alveolar pressure (Zone 3, dependent portion of lungs). Thus, the tip of the catheter should ideally be positioned below the level of the left atrium. Marked respiratory variation may indicate that the catheter is above Zone 3 and that readings are not as reliable. If there is excessive respiratory variation, it may be necessary to use the actual wave tracing to determine the pressures. The position of the tip can be seen on a lateral CXR if necessary.
- In most cases the effects of PEEP on pressure measurements are clinically insignificant. This is especially true if the catheter is positioned in Zone 3. If excessive PEEP is a concern, the PCWP can be estimated by subtracting 1/2 the PEEP level from the PCWP if lung compliance is normal or 1/4 of PEEP level if lung compliance reduced. It is not advisable to eliminate PEEP temporarily for pressure measurement as this may compromise respiratory function and induce hemodynamic instability.
- PCWP and CVP tracings should be examined, and if a large V wave is seen (indicating significant valve regurgitation), the atrial pressures (ventricular end-diastolic pressures) should be determined by examining the actual tracings to determine the pressure during diastole to make certain the large V wave doesn't falsely elevate the pressure the monitor displays.
- It is important that no air be in the PAC lumens or pressure tubing. Air will cause the waveforms to be "damped" and the pressures to be inaccurate.
- If the PAC wedges with the balloon only partially inflated (less than 1 cc), the catheter is too far distally in the pulmonary artery. The PAC needs to be repositioned by withdrawing the catheter approximately 5–10 cm and then advancing the catheter with the balloon fully inflated until the PCWP appears.
- When obtaining a PCWP, the bedside nurse should always inflate the balloon slowly and stop when a PCWP is obtained. This will prevent the rare complication of pulmonary artery rupture that can occur when the PAC has migrated distally into a small artery and the balloon is suddenly fully inflated.
- The bedside nurse should be able to identify a continuous PCWP in the event the catheter migrates distally and become inadvertently continuously "wedged." Unrecognized continuous PCWP can lead to pulmonary infarction as a result of ischemia or pulmonary rupture if the balloon is suddenly fully inflated with the catheter in this position, especially in patients with pulmonary hypertension. To lessen the risk, always assure that the balloon is completely deflated after wedging and that the PAC does not extend 5 cm beyond midline on chest X-ray.
- If air is injected into the balloon with little resistance, or no air can be withdrawn, the balloon is most likely ruptured, and no more air should be injected. If needed, the PAC should be changed.
- The PAC should never be left in the right ventricle, as it may result in ventricular arrhythmias or right heart block. This can also occur during insertion and can result in complete heart block in patients with pre-existing left heart block, making it imperative that the operator have appropriate resuscitation equipment when inserting a PAC in any patient with left heart block.
- If at any time you can't withdraw the PAC, obtain a CXR to rule out that the PAC has become knotted (rare). If confirmed, a vascular surgeon or interventional radiologist should be consulted.
- Don't advance the PAC without the balloon inflated, as in rare cases this can lead to pulmonary or cardiac perforation.
- In unrecognized cardiac tamponade, the *x* descent (isovolumetric atrial relaxation) in the right atrial waveform appears exaggerated because of the drop in pericardial pressure during ventricular systole, whereas the *y* descent (passive flow from atria to ventricles in early diastole) appears blunted because the pericardial pressure remains constant during ventricular diastole.
- Fluoroscopy or cardiac ECHO may be helpful in placing a PAC in patients with tricuspid valve regurgitation, a very large right atrium or ventricle, or when using a femoral vein approach.

15 Arterial Line

James Bardes and Lydia Lam

15.1 General Principles

- Arterial lines are indicated for continuous invasive blood pressure monitoring or in patients that require frequent arterial blood sampling. The invasive blood pressure measurement is more accurate than the noninvasive sphygmomanometric measurement, especially in the critically ill.
- Consent should be obtained, if possible.
- Complications include catheter dislodgement and bleeding, hematoma, thrombosis, false aneurysm, peripheral tissue ischemia and necrosis, and infection.
  - Although rare, the most serious complication is the development of ischemia and necrosis of the extremity, usually the fingers or toes. Extremity ischemia can occur due to embolization by a dislodged clot or atheromatous debris or due to fragmentation of the catheter.
  - Routine monitoring of perfusion to the distal extremity should be performed.
- The radial artery is the most commonly accessed vessel followed by the femoral artery, in both adults and children.
  - Alternative sites of insertion include the ulnar, brachial, and the dorsalis pedis.
  - Caution should be used when accessing the ulnar artery, because this is the dominant artery to the hand in 95% of patients. In the presence of poor collateral flow, or an occlusion of the radial artery, the hand can become ischemic. The adequacy of the collateral circulation can easily be assessed by performing the Allen's test (see radial artery catheter).
- Arterial catheterization is contraindicated by lack of arterial pulse, inadequate collateral flow or circulation to an extremity, infection at the catheter site, and the presence of a synthetic vascular graft.
- Use of ultrasound guidance improves cannulation rates, especially in patients with not easily palpable pulses.
  - A straight linear array probe is preferred for vascular imaging.
  - These probes produce higher frequencies (5–13 MHz), which provide better resolution for blood vessels.
  - Color Doppler can be used to confirm flow within the artery (Fig. 15.1).

J. Bardes · L. Lam (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: James.bardes@med.usc.edu; Lydia.lam@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_15

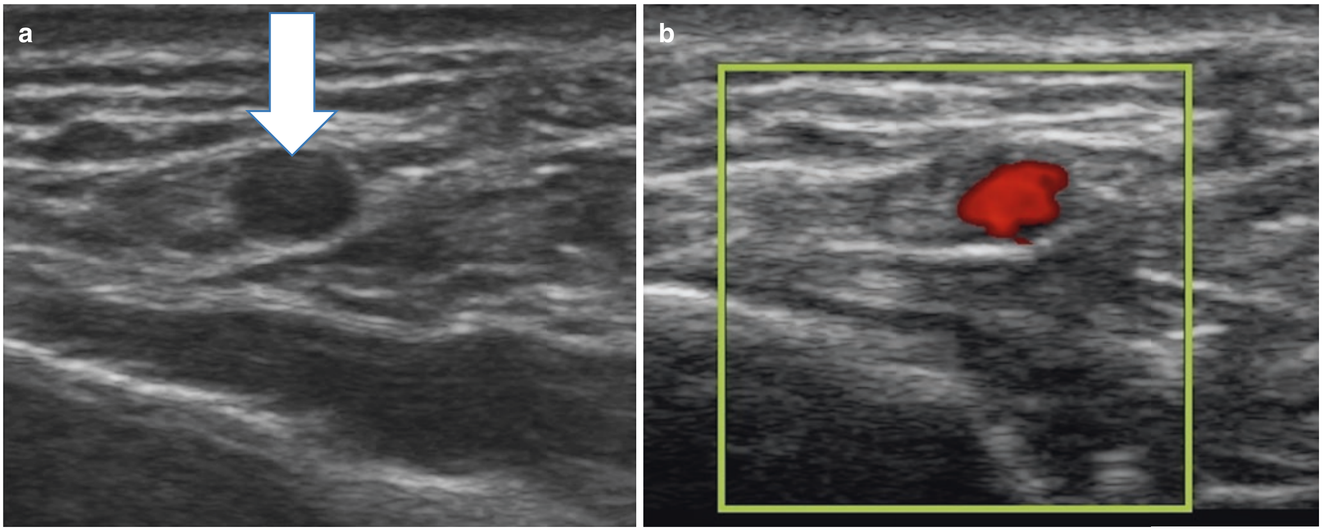


Fig. 15.1 Ultrasound of the radial artery (white arrow). Note the color Doppler in (**b**) identifies flow within the artery

15.2 Radial Artery Catheter

- The Allen's test should always be performed to confirm adequate collateral circulation to the hand (Fig. 15.2).
  - Elevate the hand for approximately 30 seconds.
  - Apply pressure over the radial and ulnar arteries simultaneously to occlude flow distally. The hand should appear pale.
  - Pressure is released from the ulnar artery. The skin color to the hand should return within a few seconds.
  - If color does not return to the hand within a few seconds, the ulnar artery does have sufficient flow to fully perfuse the hand. In this case, it is unsafe to place a radial arterial line.
- The patient's arm and wrist should be extended with the palmar surface visible. A small towel may be rolled and placed under the wrist to achieve correct positioning. However, overextension of the wrist may make the artery more difficult to palpate (Fig. 15.3).
- Puncture sites should be over the radial pulse, as distal as possible, about 1 cm proximal to the radial styloid process.

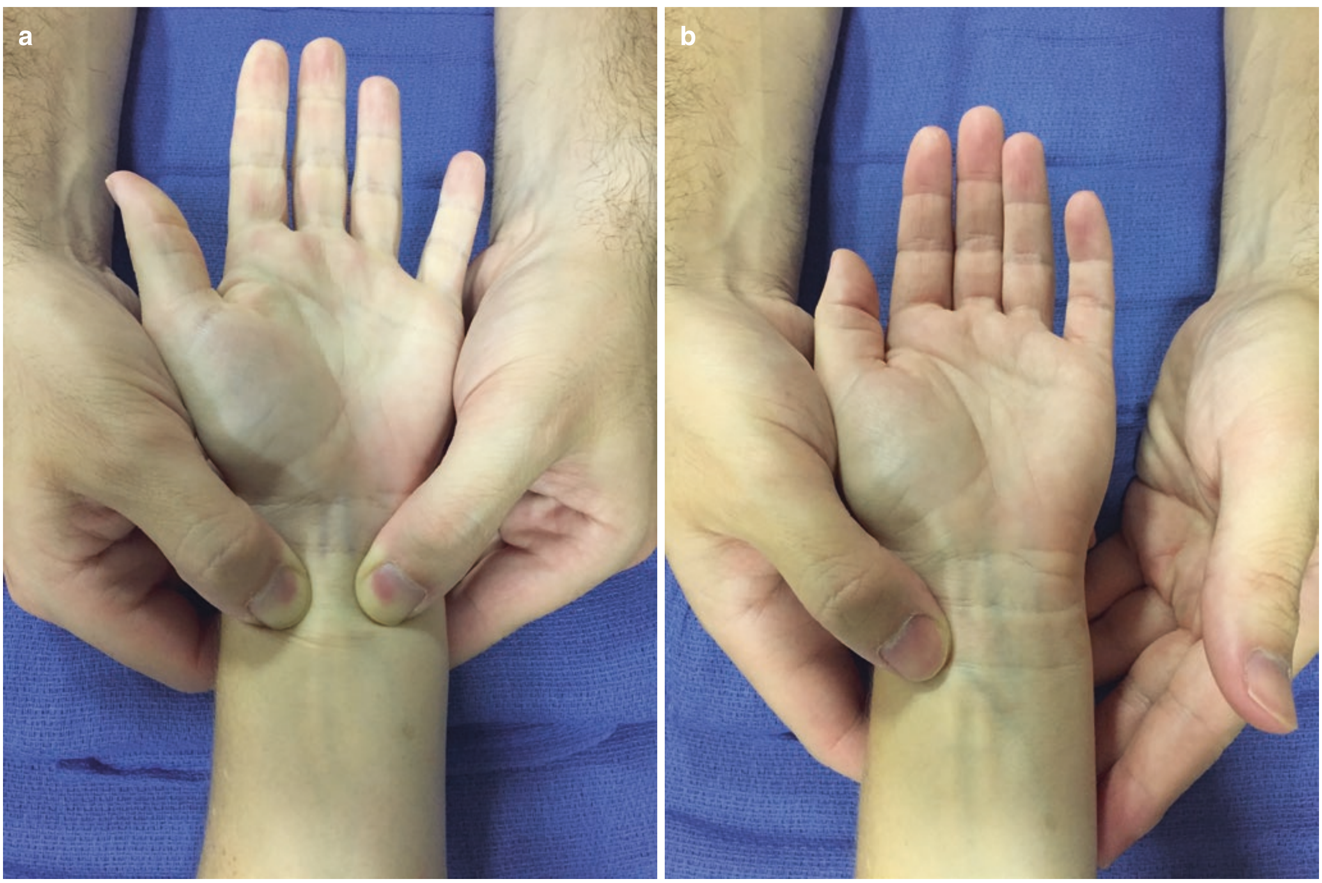


Fig. 15.2 Allen's test. (**a**) Pressure is applied to the radial and ulnar arteries simultaneously until the hand appears pale. (**b**) After releasing the pressure on the ulnar artery, the color returns to the hand. This demonstrates adequate flow from the ulnar artery to the hand; a radial arterial line can safely be placed

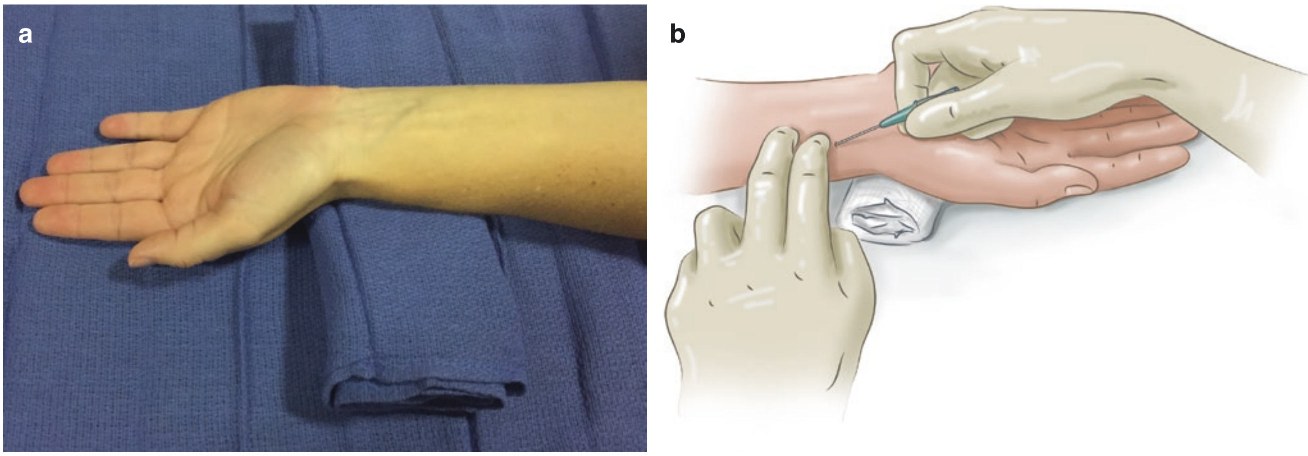


Fig. 15.3 Positioning for radial arterial line placement. Note the slight extension of the wrist with a small towel underneath

15.3 Brachial Artery Catheter

- The patient should be supine and the arm extended (Fig. 15.4).
- The artery can be palpated, or identified with ultrasound, proximal to the antecubital fossa and between the heads of the biceps and triceps.

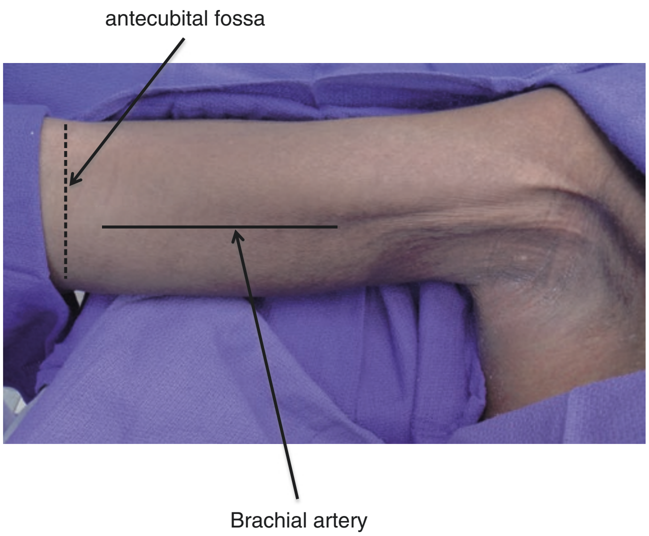


Fig. 15.4 Positioning for a brachial arterial line. The solid line represents the space between the heads of the biceps and triceps

- Care should be taken when selecting the brachial artery for cannulation; the median nerve travels adjacent to the vessel and may be injured.

15.4 Femoral Artery Catheter

- Patients should be placed supine with slight external rotation of the selected hip if possible.
- The key anatomic landmark for the femoral artery is the inguinal ligament, which extends from the anterior superior iliac spine to the pubic tubercle. The external landmark for the femoral artery is the middle of the inguinal ligament. The puncture site should be about 2–3 cm below the middle of the inguinal ligament (Fig. 15.5).
- Within the femoral triangle, the artery is lateral to the femoral vein and medial to the femoral nerve.
  – The anatomy of the femoral triangle can be remembered by the mnemonic VAN from medial to lateral (vein, artery, nerve).

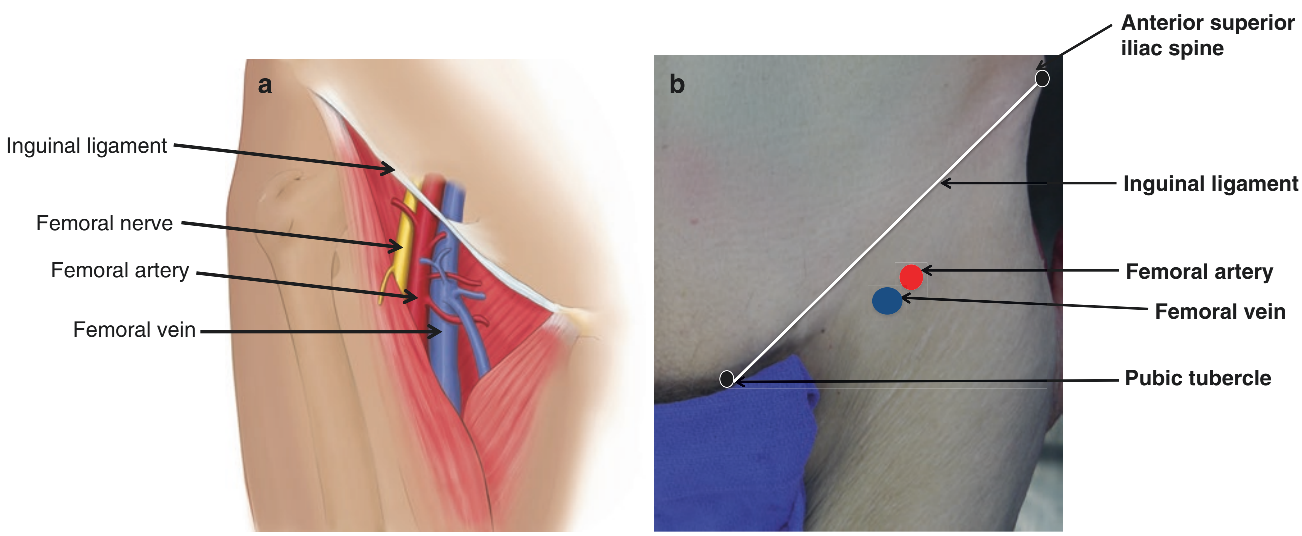


Fig. 15.5 (**a**, **b**) Landmarks for femoral artery catheter placement

15.5 Dorsalis Pedis Artery Catheter

- The patient should be supine with a slight extension of the ankle joint.
- The dorsalis pedis can be palpated lateral to the extensor hallucis longus tendon on the dorsal surface of the foot (Fig. 15.6).
- Adequacy of the collateral flow to the foot can be assessed by occlusion of the dorsalis pedis artery and compression of the nail bed of the big toe for a few seconds. The color of the nail bed should return to normal as soon as the pressure is released.

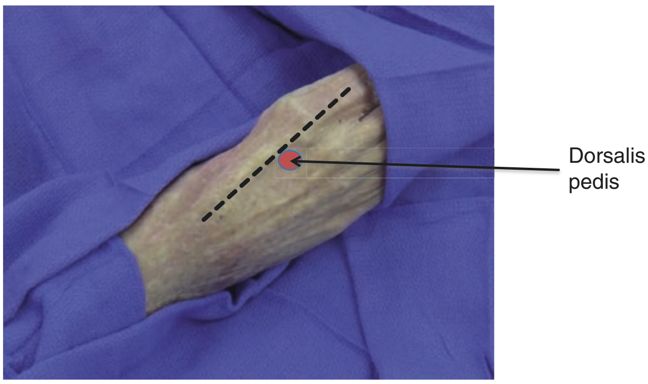


Fig. 15.6 Positioning for dorsal pedis placement, dashed line indicates the extensor hallucis longus tendon

15.6 Equipment

- Ultrasound machine, if ultrasonic guidance will be used.
- Arterial line kits are commercially available. Most kits include an 18 g Seldinger needle, a guidewire, in some cases a dilator, and a catheter (Fig. 15.7).
- There are several commercial devices that include self-contained guidewires and allow performance of a modified Seldinger technique (Fig. 15.8).
- The operator should don full universal sterile precautions.
- Chlorhexidine prep, sterile towels, drapes, gauze, and sterile ultrasound covers should be available.

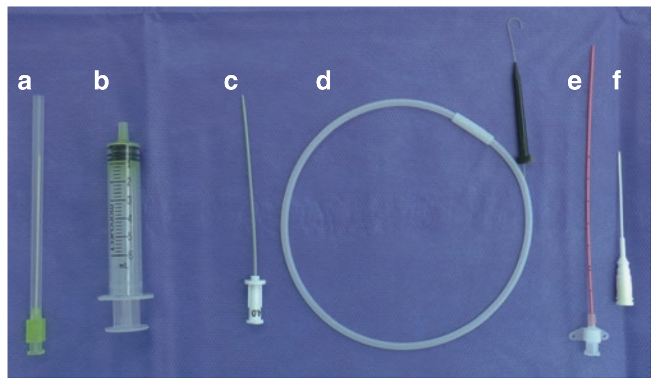


Fig. 15.7 Equipment needed for an arterial line placement. (A) Seldinger needle, (B) syringe, (C) dilator, (D) guidewire, (E) femoral catheter, (F) radial catheter

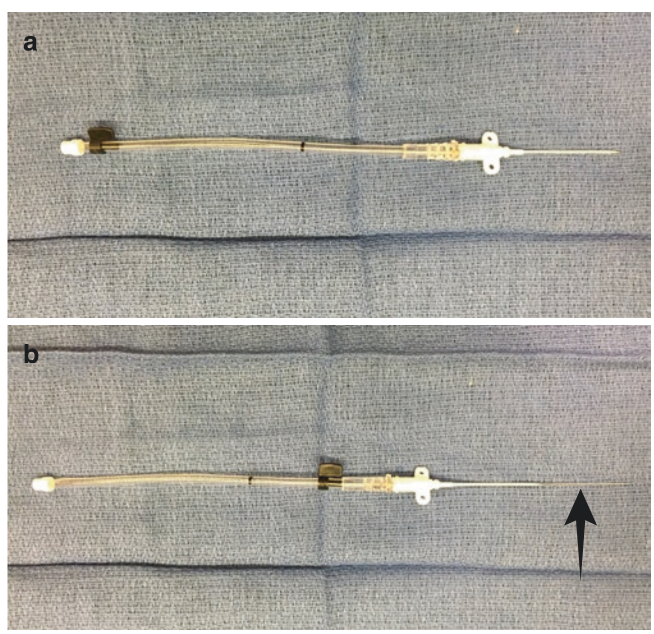


Fig. 15.8 Device with self-contained guidewire. Note the arrow identifying the extended guidewire in Fig. B

15.7 Procedure

- The artery is palpated or identified with ultrasound.
- Chlorhexidine antiseptic should be applied widely and then sterile drapes placed.
- Local anesthetic should be injected over the cannulation site with a 27 g needle. About 1 milliliter of 1% plain lidocaine is recommended.
  - Too much local anesthetic can obscure the vessel either to palpation, or the image if using ultrasound.
- The arterial catheter can be placed by direct insertion or by a Seldinger technique.

15.8 Direct Insertion Technique (Catheter over a Needle)

- This is the preferred technique for radial artery or dorsalis pedis artery cannulation.
- This technique requires either a needle with angiocatheter or a device used for the modified Seldinger technique.
- The artery is palpated with the non-dominant hand, while the dominant hand inserts the intravascular needle/catheter, at an angle of 30–45°, until pulsatile blood is obtained (Fig. 15.9). The catheter is then advanced into the artery, and the inner needle is removed (Fig. 15.10).

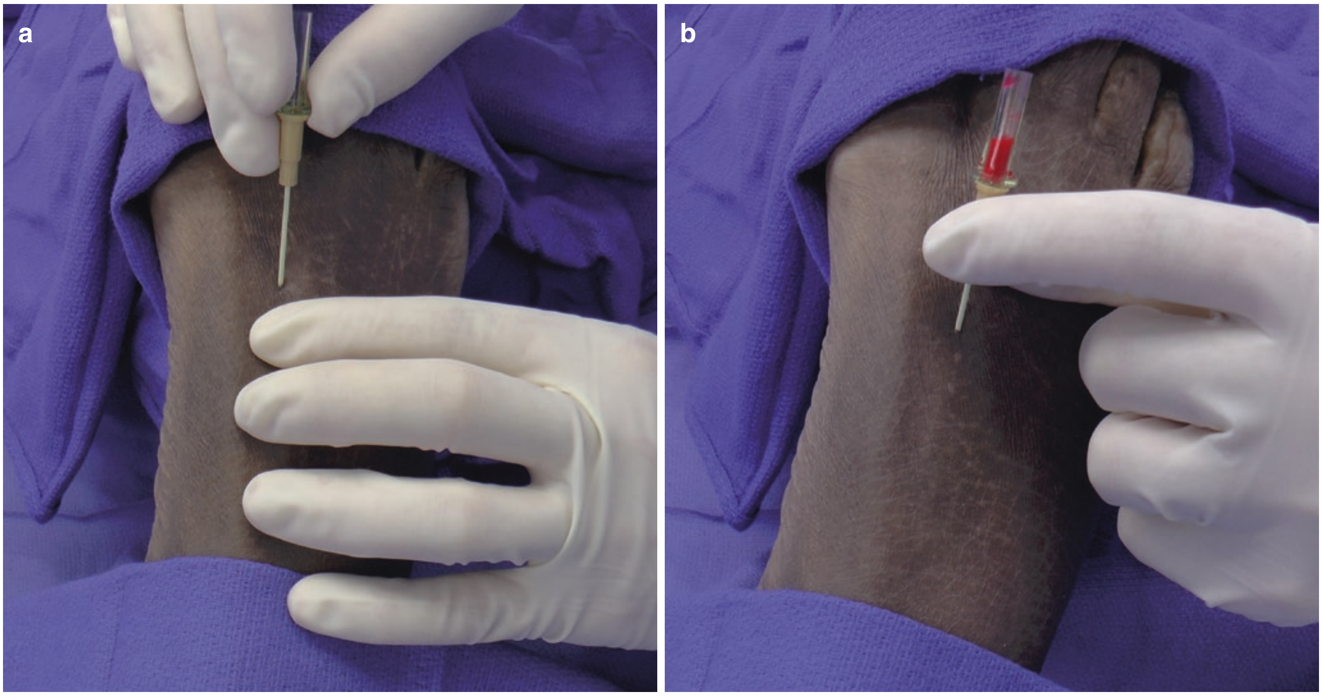


Fig. 15.9 Direct insertion of a dorsalis pedis arterial line. (**a**) The vessel is accessed at a 30–45° angle (**b**) until bright-red blood returns

Fig. 15.10 Direct insertion of a dorsalis pedis arterial line. After accessing the vessel the catheter is advanced over the needle into the vessel

15.9 Seldinger Technique (Catheter over Guidewire)

- This is the preferred method for femoral or brachial artery cannulation.
- An 18 g needle is used to access the vessel at a 45° angle until a flash of bright-red blood is seen in the needle hub (Fig. 15.11).
- After a flash of bright-red blood is seen, the needle should be lowered to an angle closer to 20–30°. It is important to hold the needle very steadily in position; otherwise, the tip may leave the artery.
- A guidewire is then advanced into the artery, and the needle is removed over the wire (Fig. 15.12).

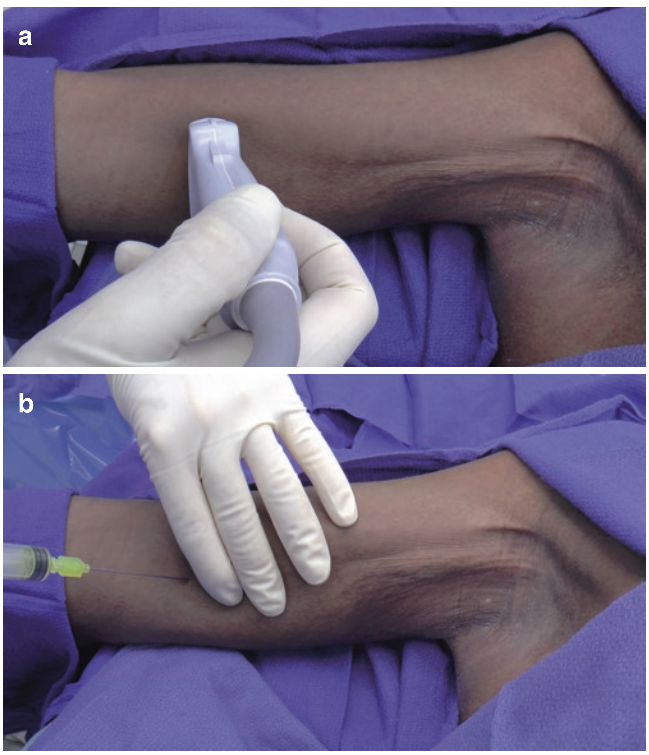


Fig. 15.11 Seldinger technique to place a brachial arterial line. (**a**) A linear ultrasound probe can be used to identify the vessel. (**b**) An 18 g needle is used to access the vessel at a 45° angle until a flash of bright-red blood is seen in the needle hub; in this case the artery is identified by palpation

Fig. 15.12 Seldinger technique to place a brachial arterial line. A guidewire is advanced into the artery and the needle removed over the wire

- If a dilator is used it should only be used to dilate the soft tissue. These are commonly used with femoral catheters.
- A small skin incision is made at the site of the needle entry, to facilitate the insertion of the catheter through the skin and avoid kinking of the catheter during its advancement (Fig. 15.13).
- The catheter is advanced over the guidewire into the artery. A gentle twisting motion may help the catheter pass through the tissue. The guidewire is then removed, and bright-red pulsatile blood should be visualized.
- The catheter should pass smoothly over the guidewire. If resistance is met, the operator should reassess correct placement of the guidewire (Fig. 15.14).

Fig. 15.13 Seldinger technique to place a brachial arterial line. A small skin incision is made at the site of the needle skin entry

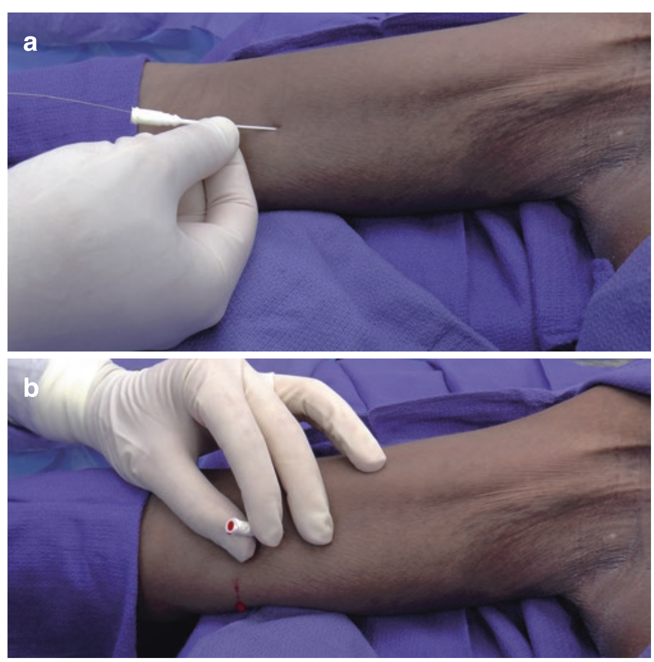


Fig. 15.14 Seldinger technique to place a brachial arterial line. (**a**) A catheter is advanced over the guidewire (**b**) and the guidewire removed

15.10 Modified Seldinger

- This technique is performed with devices that have built-in guidewires.
- The artery is punctured in a similar fashion to the Seldinger technique (Fig. 15.15).
- Once a flash of blood returns, the angle is again lowered to 20–30°. The built-in guidewire is then advanced fully (Figs. 15.16 and 15.17).
- The catheter can then be advanced over the wire (Fig. 15.18).
- Lastly the wire and needle assembly are removed together.
- Once in place, the catheter is connected to a pressurized bag of normal saline connected to a pressure transducer.
- The arterial line should be sutured in place and a sterile dressing applied.

Fig. 15.15 Modified Seldinger technique, inserting a radial arterial line. The artery is punctured in a similar fashion to the Seldinger technique

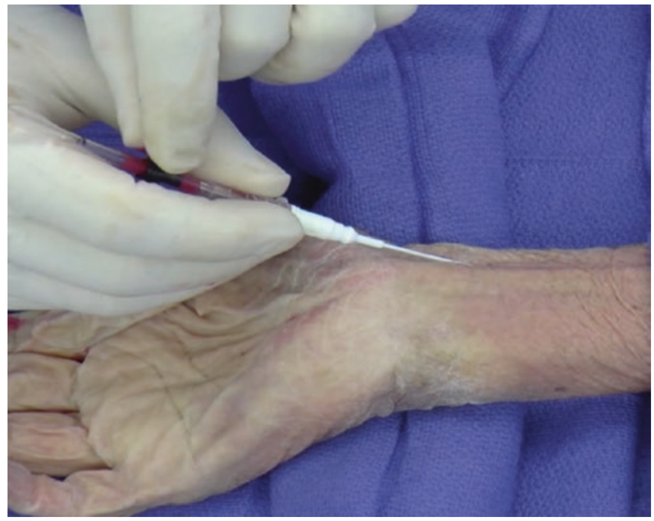


Fig. 15.17 Modified Seldinger technique, inserting a radial arterial line. The internal guidewire is advanced

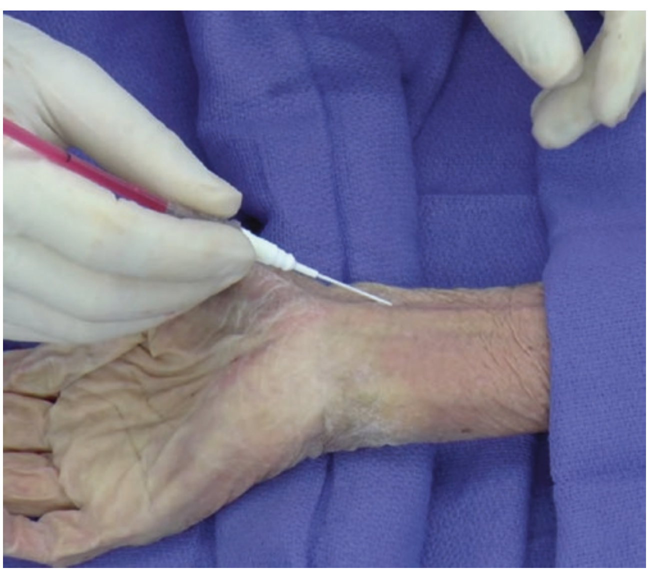


Fig. 15.16 Modified Seldinger technique, inserting a radial arterial line. Once a flash of blood returns, the angle is lowered to 20–30°

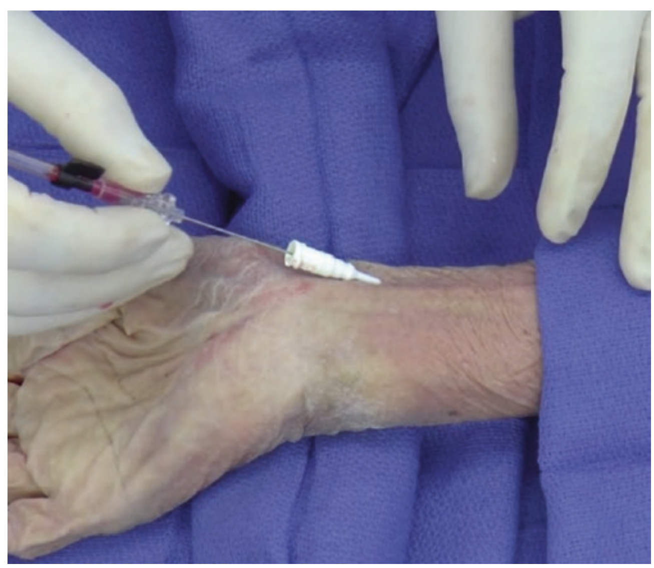


Fig. 15.18 Modified Seldinger technique, inserting a radial arterial line. The guidewire and needle assembly are removed

15.11 Blood Pressure Monitoring

- Blood pressure is monitored by measuring the pressure wave transmitted by the arterial pulse, through a fluid-filled tube, connected to a pressure transducer.
- The tubing that connects the catheter to the pressure transducer is not normal IV tubing. Normal IV tubing is too compliant and will not allow accurate measurements. The tubing should be non-compliant to allow proper transducing of the pressure wave. The tubing should be less than 1.2 m (4 ft) for the most accurate reading. Longer tubing may make the blood pressure appear elevated.
- The transducer must be "leveled" at the patients' bedside and aligned with the aortic root; externally this means alignment with midaxillary line in the 4th intercostal space. If the transducer is higher than this, the blood pressure will appear lower, and alternatively if the transducer is lower, the blood pressure will appear elevated. Leveling will need to be adjusted whenever the patients positioning is adjusted in bed.
- The transducer is "zeroed" prior to measuring blood pressures. This exposes the transducer to atmospheric pressures and sets that point as zero. If not properly zeroed, the reported blood pressure will be significantly elevated.
- Waveform (Fig. 15.19)
  - The normal waveform shape may vary depending on the caliber of the cannulated artery. However, the MAP remains the same throughout the arterial tree.
  - Over-damping of the catheter and the tubing system results in a muted waveform, which underestimates the systolic pressure and overestimates the diastolic pressure. The mean arterial pressure remains the same. The pressure waveform appears flattened. This may be caused by air bubbles or blood clots in the system, the tube kinking, loose connections, or vasospasm.
  - Under-damping leads to falsely elevated systolic pressures and lower diastolic pressures. The mean arterial pressure remains the same. The waveform has a steep systolic upstroke, a narrowed systolic peak, and rapid diastolic run off. This can be caused by hypothermia, tachycardia and arrhythmias, and in patients with severe atherosclerosis.
  - Some damping effect is normal and preferred in the pressure waves. A good measure of the damping effect is the square wave test (fast flush test) (Fig. 15.20).
    - Begin by flushing the arterial line. The wave will appear as a square. Then watch for the oscillations that occur when the flush is stopped.
    - A properly damped arterial line will have 2–3 oscillations immediately after the square wave disappears. The tracing will then return to a normal arterial waveform. A distinct dicrotic notch should be present.
    - An overdamped waveform will have only one oscillation after the square wave, and the dicrotic notch will disappear.
    - Under-damped lines will have multiple oscillations after the square wave, and multiple notches can be seen in the waveform.
  - Understanding the damping effect is important to the provider when making clinical decisions about blood pressure management or when setting blood pressure goals.
- Troubleshooting should follow a systematic check of the transducing system.
  - Ensure all cables are securely connected.
  - The system can be re-zeroed and then the arterial tubing flushed.
  - The patient's hand position should also be checked. Excessive extension or flexion can kink the catheter causing the waveform to be severely dampened.

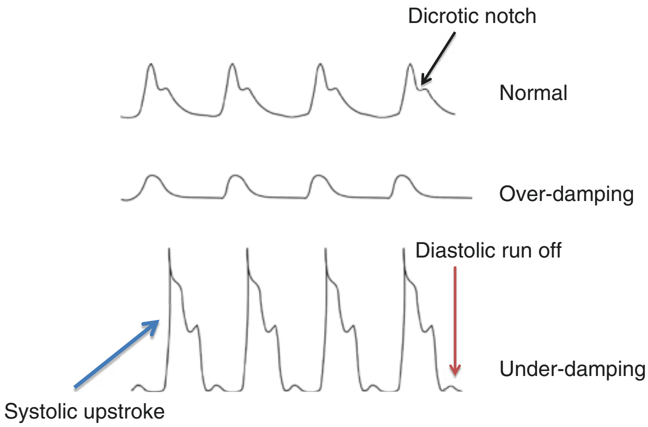


Fig. 15.19 Illustrations demonstrating damping effects on arterial waveforms

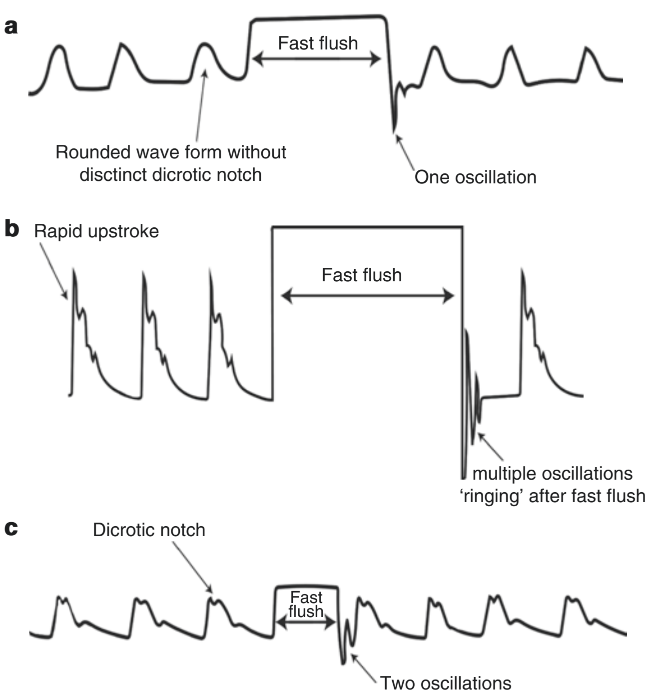


Fig. 15.20 Illustration of the square loop test

15.12 Tips/Pitfalls

- After several attempts at cannulation, the artery will spasm, making catheter placement difficult. A short time should be allowed to pass before attempting placement again.
- Occasionally after advancing the catheter, no blood flow will be present after the guidewire is removed. It is possible that the practitioner has advanced the catheter through the posterior wall of the vessel inadvertently. The transfixation technique can then be applied.
  – The catheter is slowly retracted until blood flows freely from the end of the catheter.
  – A guidewire can then be advanced through the catheter into the vessels. The catheter is then advanced over the guidewire.
  – The guidewire can then be removed.
- If there is resistance during insertion of the guidewire, rotate the needle gently and try advancing the guidewire again. No force should be used.
- Inspect the extremity on a frequent basis for any signs of peripheral ischemia. If there are any signs of ischemia, remove the catheter immediately
- Remove the catheter as soon as possible to reduce complications.
- After catheter removal direct pressure should be held for 5–10 min, longer if the patient is coagulopathic. After removal, the catheter should always be inspected to ensure it is intact. The puncture site and pulse should be evaluated in about 15–20 minutes for hematoma or extremity ischemia.

Pericardiocentesis

16

Meghan Lewis, Subarna Biswas, and David Shavelle

16.1 Surgical Anatomy

- The pericardium is a thin, double-walled sac surrounding the heart and the roots of the great vessels. It is bordered inferiorly by the diaphragm, laterally by the pleural sacs, anteriorly by the sternum, and superiorly by the roots of the great vessels. It is fixed at the root of the great vessels (Fig. 16.1).
- The pericardial cavity contains a small amount (<50 mL) of pericardial fluid under normal physiologic conditions (Fig. 16.1).
- Surface anatomic landmarks for pericardiocentesis include the xiphoid process and the fifth and sixth ribs at the sternocostal junction (Fig. 16.2).
- A pericardial effusion can be visualized sonographically in several views:
  – Subxiphoid
  – Apical four-chamber
  – Parasternal
- A subxiphoid view is obtained inferior to the xiphoid process, with the probe directed at the patient's left shoulder (Fig. 16.3).
  – The right atrium and ventricle appear in the near field, and the left atrium and ventricle in the far.
  – The myocardium appears gray, while blood-filled chambers appear black/hypoechoic.
  – Fluid (effusion) appears as an anechoic stripe around the heart.
- An apical view is obtained in the fifth intercostal space at the point of maximal impulse (Fig. 16.4). The probe is directed to the patient's left back:
  – The apex is closest to the probe.
  – Both ventricles appear in the near field and both atria in the far.
- A parasternal view is obtained between the third and fifth intercostal spaces just to the left of the sternum (Fig. 16.5). The probe is directed toward the patient's right shoulder:
  – The right ventricle is in the near field, followed by the left ventricle and aortic outflow tract. The left atrium is in the far field.
  – The probe can also be rotated 90 degrees clockwise to visualize the heart in short axis. The right and left ventricles are then seen side by side.

M. Lewis (✉) · S. Biswas
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: meghan.lewis@med.usc.edu

D. Shavelle
Division of Cardiovascular Medicine, University of Southern California, Los Angeles, CA, USA

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_16

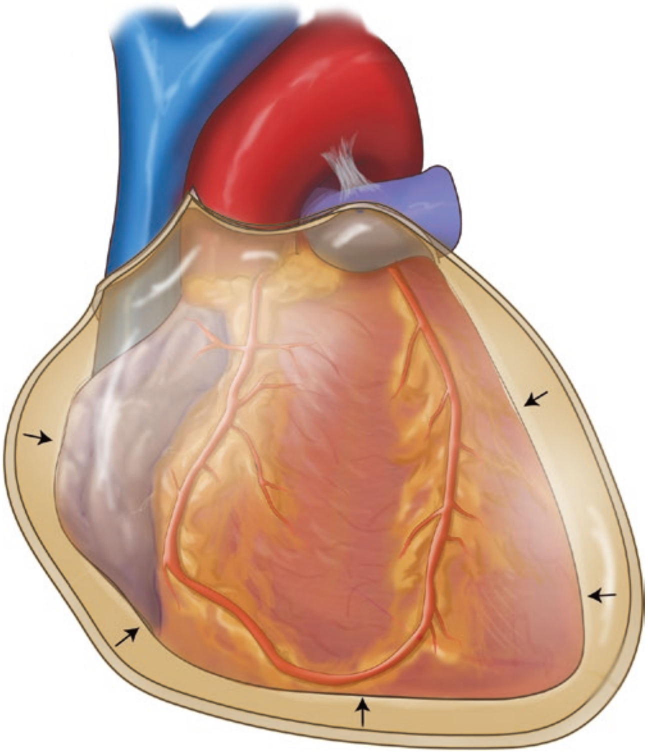


Fig. 16.1 Anatomy of the pericardium

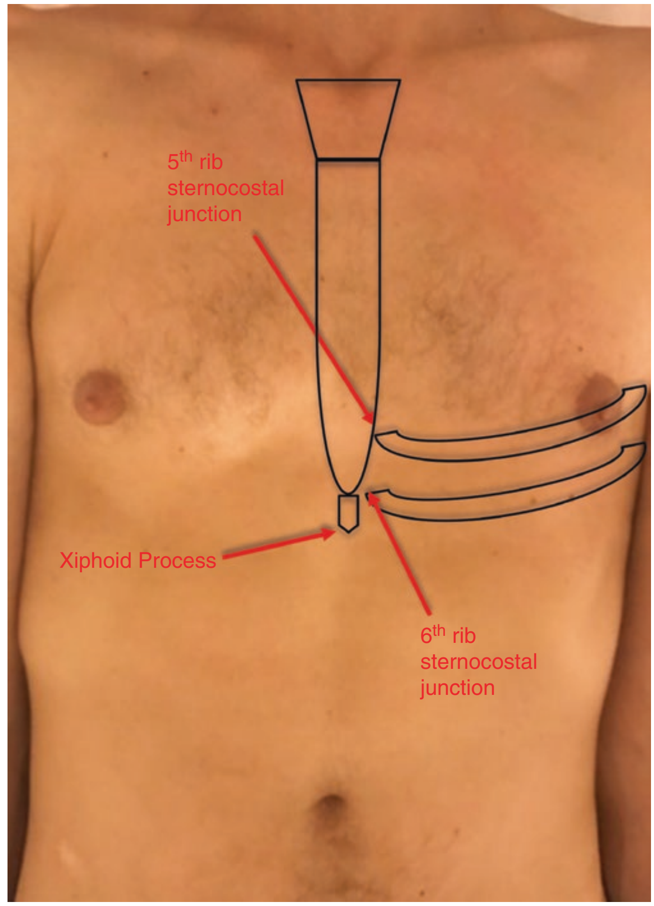


Fig. 16.2 Surface anatomic landmarks for pericardiocentesis

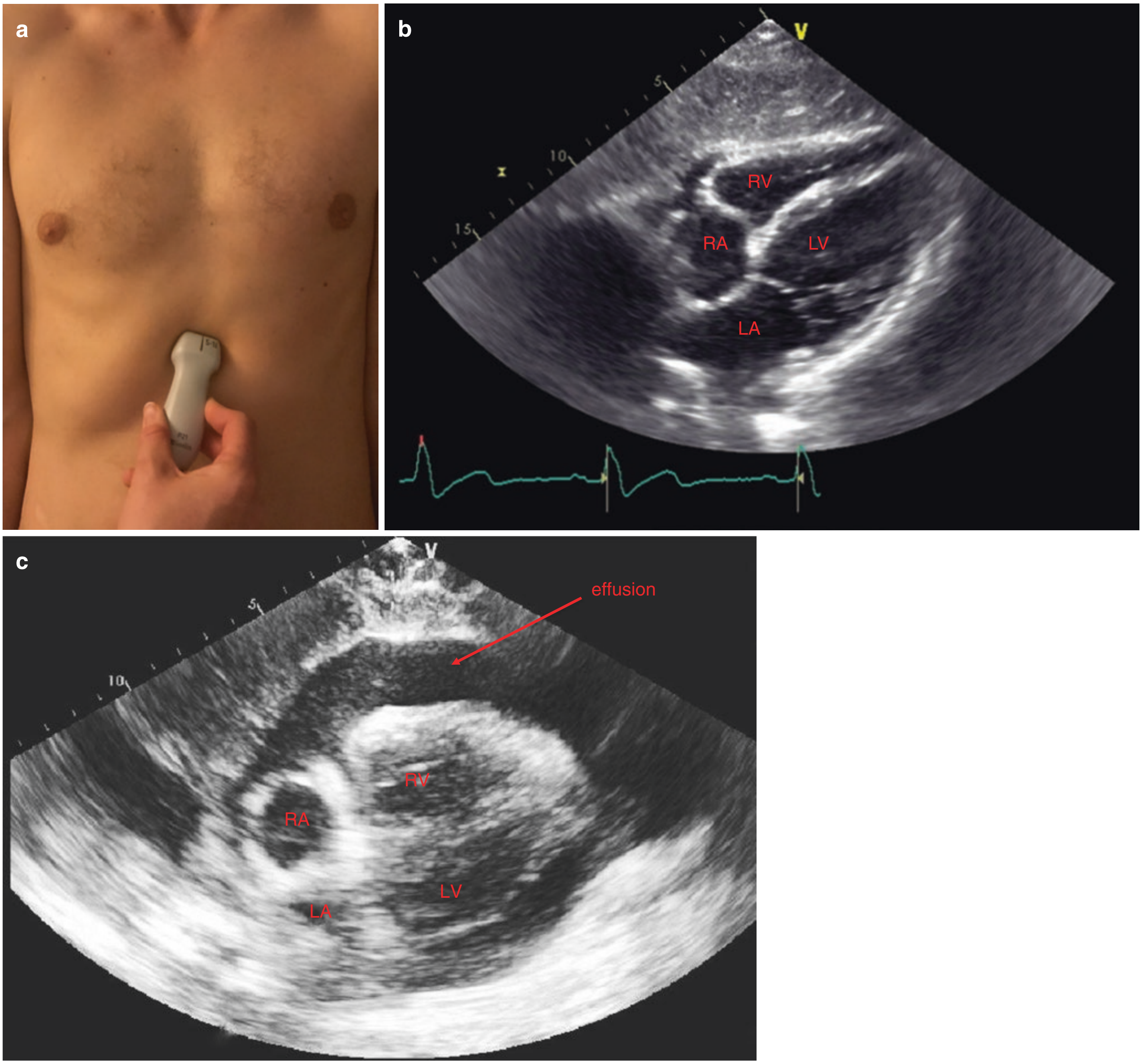


Fig. 16.3 (**a**) Subxiphoid probe position. (**b**) Normal ultrasound image subxiphoid view. (**c**) Subxiphoid view with pericardial effusion

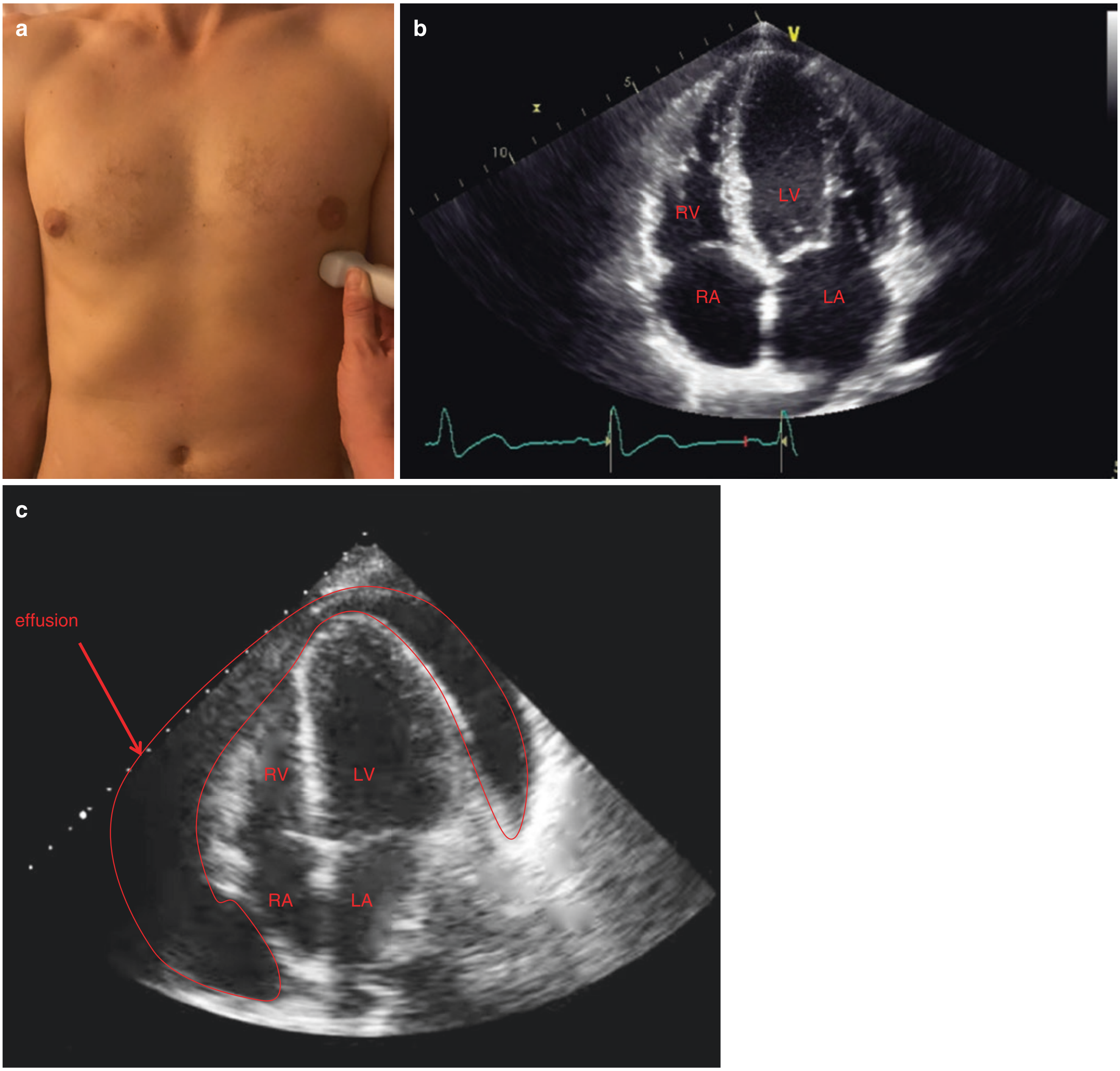


Fig. 16.4 (**a**) Apical probe position. (**b**) Normal ultrasound image apical four-chamber view. (**c**) Apical view with pericardial effusion

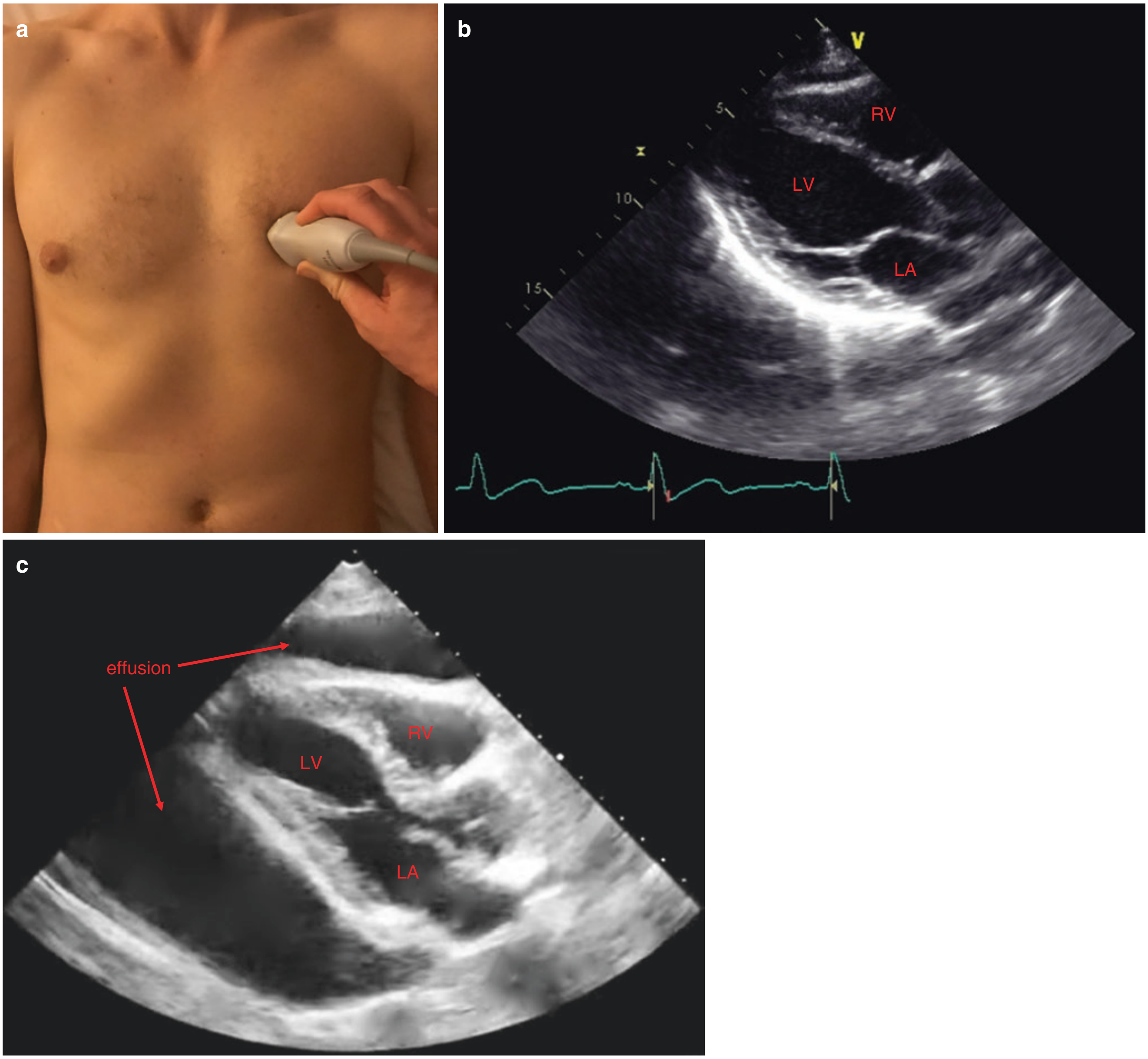


Fig. 16.5 (**a**) Parasternal probe position (long axis). (**b**) Normal ultrasound image parasternal (long axis) view. (**c**) Parasternal view with pericardial effusion

16.2 General Principles

- A pericardial effusion is an abnormal accumulation of fluid in the pericardial cavity. If it develops over a chronic period of time, the pericardium can dilate to accommodate the fluid. However, if it occurs acutely, rapid hemodynamic compromise ensues due to cardiac compression.
- Common causes of pericardial effusion include:
  - Acute: trauma, cardiac rupture, or iatrogenic injury
  - Subacute: uremia, infectious, or pericarditis
  - Chronic: autoimmune, inflammatory, and neoplastic process
- Indications for pericardiocentesis include:
  - Therapeutic: pericardial effusion with hemodynamic compromise/cardiac tamponade
  - Diagnostic
  - Palliative
- Consent from the patient or family member should be obtained whenever possible. Risks include:
  - Arterial or ventricular puncture
  - Liver injury
  - Gastric perforation
  - Pleural effusion
  - Pneumothorax
- Elective procedures should be performed under full sterile precautions, including full-body draping, gown, mask, and sterile gloves. Skin disinfection with chlorhexidine is superior to alcohol or Betadine. The ultrasound probe should be covered with a sterile probe cover. The skin entry site should be covered with dry gauze or transparent breathable dressing.
- Patients should be on supplemental oxygen and telemetry during placement.
- The operator should ensure appropriate intravenous access prior to the procedure (if the patient is hemodynamically stable).
- Nasogastric decompression is recommended, when possible, to decrease the likelihood of gastric perforation.
- Ultrasound guidance should be considered the standard of care. Determine the most superficial and largest pocket of fluid for aspiration.

16.3 Instruments

- Commercially available kits exist for pericardiocentesis/drainage. The operator should ensure familiarity with the specific product prior to use.
- General contents of a kit include (Fig. 16.6):
  - 18–20 gauge spinal or alternate needle
  - 60 cc syringe
  - Three-way stopcock
  - Flexible guidewire
  - Dilator
  - 6–8 Fr silastic drainage catheter
- Additional equipment which may not be included in the kits:
  - Chlorhexidine prep
  - Sterile drapes, gloves, mask, and gown
  - Local anesthetic
  - Appropriately sized needles
  - Additional syringes
  - Sterile saline
  - Resuscitation equipment ("code cart")
- Ultrasound equipment
  - Phased array cardiac or low-frequency (2–4 MHz) probe for optimal resolution of structures
  - Sterile probe cover

Fig. 16.6 Commercially available pericardiocentesis kit

16.4 Positioning

- Semi-recumbent positioning with head of bed 30–45° upright is preferred, because it increases dependent pooling of fluid and brings the heart closer to the chest wall.
- Patients experiencing dyspnea due to tamponade may require more upright positioning for comfort.
- The procedure can be performed in supine position if full spinal precautions are indicated.

16.5 Technique

- The procedure should be performed under full sterile conditions, as described above, whenever possible.
- Bedside ultrasonography is used to identify the effusion (Figs. 16.3, 16.4, and 16.5).
- Lidocaine is injected with a 25 gauge needle over the intended puncture site to provide local anesthesia.
- A long spinal needle is connected to a three-way stopcock (Fig. 16.7). Alternatively, a specialized needle may be provided in the pericardiocentesis kit.
  - The ultrasound probe is held with the nondominant hand. The needle is held with the dominant hand and inserted through the incision at a 45° angle from the skin (Fig. 16.8).
  - The operator should aspirate while advancing the needle.
  - The needle is slowly advanced until the tip is seen in the fluid collection. This distance is generally less than 5 cm and can also be measured on ultrasound prior to the procedure (Fig. 16.9).
- Fluid is aspirated into the syringe (Fig. 16.10). Fluid can be emptied from the syringe by attaching tubing to the three-way stopcock (Fig. 16.7), and the procedure can then be terminated by removing the needle. Alternatively, the operator can continue with placement of a drain using Seldinger technique.
- The needle is stabilized in position with the nondominant hand, while the syringe is removed from the needle.
- The guidewire is then inserted through the Seldinger needle into the pericardium (Fig. 16.11). The wire should be advanced approximately 15–20 cm. The operator will then maintain the guidewire with the nondominant hand throughout the remainder of the procedure.
- The needle is removed. An 11 blade scalpel is used to make a small stab incision in the skin surrounding the wire (Fig. 16.12).
- A dilator is then advanced with the operator's dominant hand over the wire and into the tract. The end of the guide wire is maintained by the nondominant hand while advancing the dilator (Fig. 16.13). The dilator should not be advanced more than a few millimeters and then removed.
- The catheter should be inserted over the guidewire (Fig. 16.14).
- The guidewire should then be removed from the catheter.
- The catheter is then secured to the skin with adhesive dressing (Fig. 16.15). It can be left in place for up to 24 h.
- A portable chest X-ray should be obtained to evaluate for pleural effusion or pneumothorax.

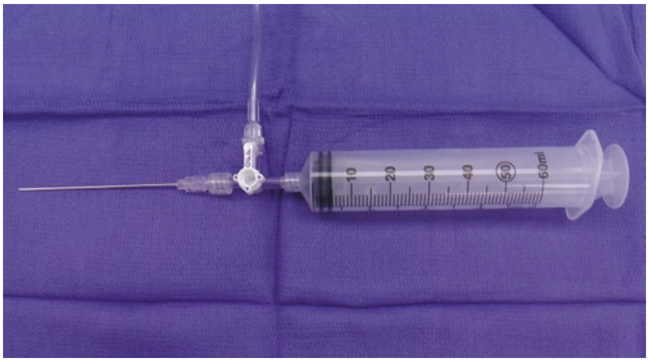


Fig. 16.7 Spinal needle/stopcock/tubing apparatus

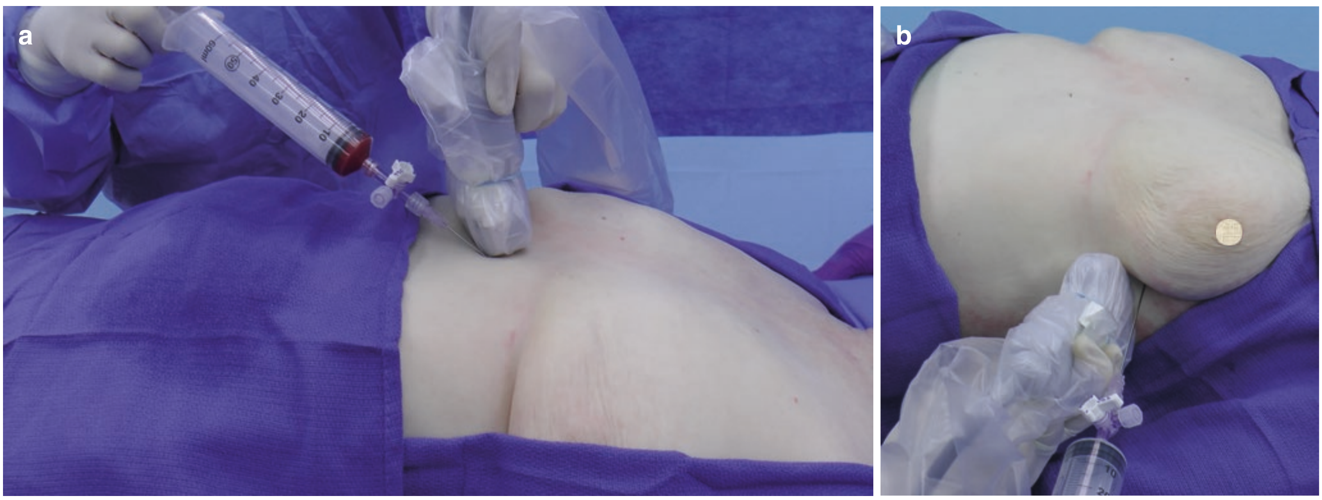


Fig. 16.8 The nondominant hand holds the ultrasound probe, while the dominant hand advances the spinal needle ((**a**) subxiphoid approach, (**b**) apical approach)

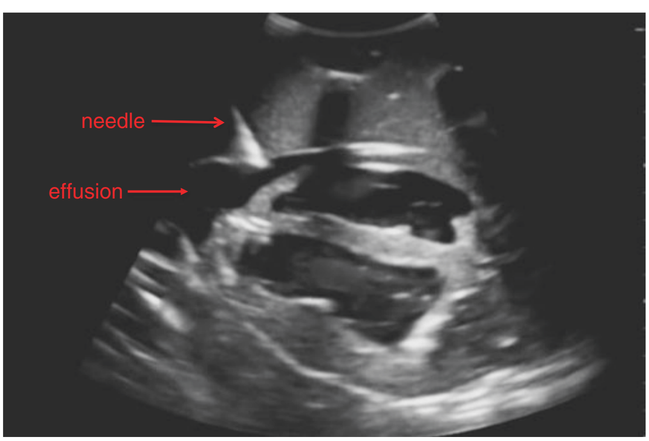


Fig. 16.9 Ultrasound view demonstrating the needle as it enters the effusion in real time. The arrow shows the tip of the needle entering the effusion

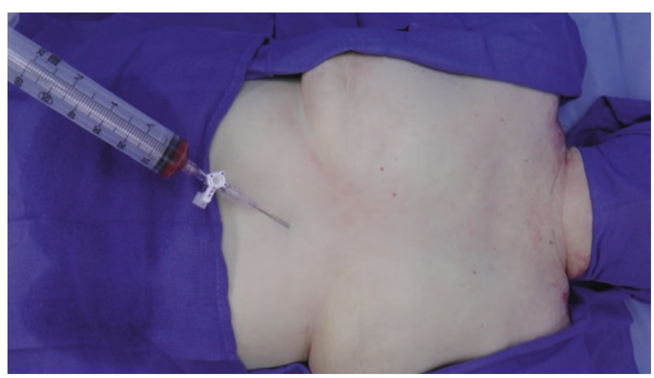


Fig. 16.10 Bloody fluid aspirated into syringe

Fig. 16.11 The wire is advanced through the Seldinger needle. The nondominant hand is used steady to the needle

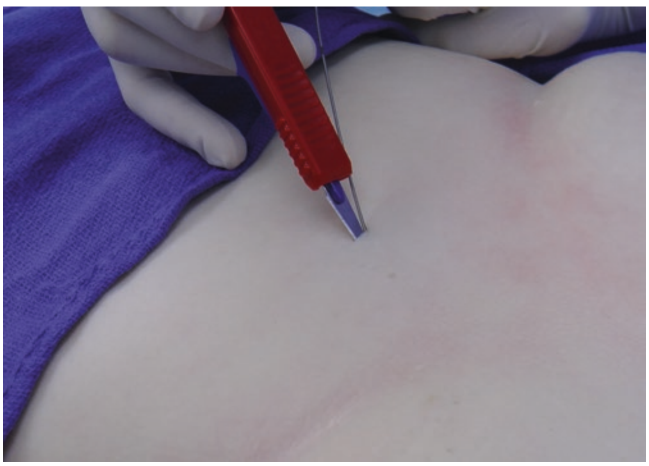


Fig. 16.12 A skin nick is made at the wire entry site

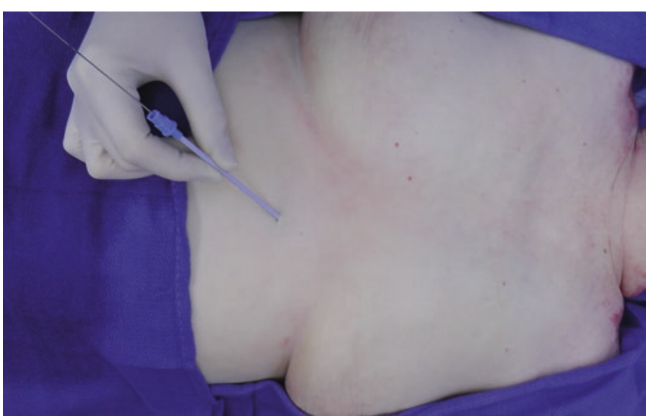


Fig. 16.13 A dilator is advanced over the guidewire. Note: the operator should maintain the end of the wire with the nondominant hand at all times

Fig. 16.14 The catheter is advanced over the guidewire to the desired length, while the free end of the wire is grasped with the nondominant hand

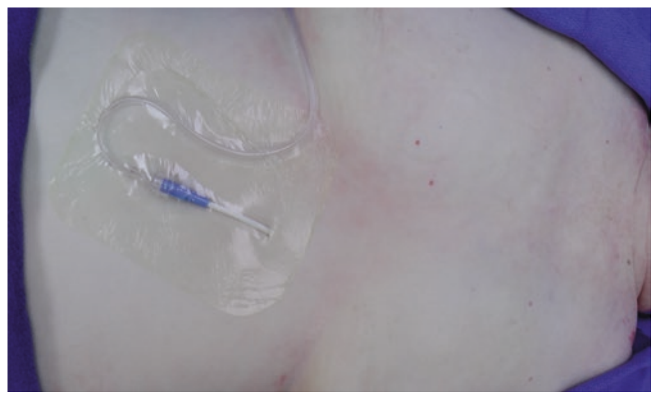


Fig. 16.15 The catheter is secured in place with an adhesive dressing

16.6 Complications

- Coronary artery or right ventricular puncture: this may be initially silent, then present with delayed hemopericardium that is poorly responsive to needle or catheter aspiration.
- Liver injury.
- Gastric perforation.
- Pleural effusion.
- Pneumothorax.
- Vasovagal response to pericardial decompression.
- Acute left or right ventricular dysfunction may be induced by successful pericardial decompression, despite no associated anatomic injury.

16.7 Tips and Pitfalls

- It is preferable to avoid the use of sedation, due to the risk for hemodynamic compromise. If sedation must be used, short-acting medications are recommended.
- Longer needles (up to 12 cm) may be required for obese patients, and shorter needles (4 cm) are appropriate for infants and small children.
- Needle tip position in the pericardial cavity can be confirmed by injection of agitated saline.
- ST elevations on telemetry during needle advancement suggest contact with the myocardium, and the needle should be slowly withdrawn.
- Relative contraindications to pericardiocentesis include myocardial rupture, aortic dissection, and severe coagulopathy (correct coagulopathy first, if possible).
- Percutaneous pericardiocentesis should not be used to evacuate frank blood or clot from around the heart, as the catheter will not allow for adequate drainage, and underlying cardiac injury cannot be addressed with this procedure. Also, removing pericardial blood may increase the driving pressure into the pericardial space.
- Loculation occurs in up to 1/3 of nontraumatic effusions. If no fluid is aspirated, the needle should be withdrawn promptly and redirected. Patient repositioning (more reverse Trendelenburg) may redistribute pericardial fluid and provide a better window for drainage. Operative intervention may be required.

17 Resuscitative Thoracotomy

Chrissy Guidry and Demetrios Demetriades

17.1 Surgical Anatomy

The major muscles, which are divided during the resuscitative thoracotomy, include the pectoralis major, the pectoralis minor, and the serratus anterior muscles.

- Pectoralis major muscle: it arises from the medial half of the clavicle, the anterior surface of the sternum, and the cartilages of all the true ribs. The 5-cm-wide tendon inserts into the upper humerus.
- Pectoralis minor muscle: it originates from the third, fourth, and fifth ribs, near their cartilages, and inserts into the coracoid process of the scapula.
- Serratus anterior muscle: it is attached to the upper eight or nine ribs and inserts into the medial part of the scapula.
- Left phrenic nerve: it descends on the lateral surface of the pericardium.
- Thoracic aorta: it is situated to the left of the vertebral column.
- Esophagus: it descends on the right side of the aorta to the level of the diaphragm, where it moves anterior and to the left of the aorta.
- Aorta: it is the first structure felt while sliding your fingers along the left posterior chest wall toward the spine.

17.2 General Principles

- In traumatic cardiac arrest, external chest compressions have little to no role. External cardiac compression produce approximately 20% of baseline cardiac output whereas open cardiac massage produces approximately 55% of the baseline cardiac output.
- Trauma patients that are admitted to the ICU and have cardiac arrest are candidates for resuscitative thoracotomy. Indications and contraindications are controversial in the setting of the intensive care unit.
- The resuscitative thoracotomy in the ICU allows for open cardiac massage, cross clamping of the aorta, release of tamponade, cardiac defibrillation, and direct control of thoracic hemorrhage.
- In ICU patients considered for a resuscitative thoracotomy usually are already intubated. If not, the patient should be rapidly intubated simultaneous to the resuscitative thoracotomy. After the endotracheal tube is placed, the tube may be advanced to the right main stem, allowing for the left lung to collapse. This reduces the risk of injury to the left lung and makes the thoracotomy easier to perform. Caution should be taken, however, because right main stem intubation could cause oxygenation problems in the presence of injured lungs.

C. Guidry · D. Demetriades (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_17

17.3 Surgical Instruments

The equipment for the resuscitative thoracotomy should be kept in an easily accessible supply closet in the surgical intensive care unit. All staff should be aware of the whereabouts of the instruments used for the procedure. Good lighting, working suction, and internal defibrillation should be ready. All personnel should wear personal protective equipment during the procedure. Since the use of resuscitative thoracotomy in the ICU is used in an emergent situation, all SICU staff should be familiar with the procedure and the equipment used.

Resuscitative Thoracotomy Tray Instruments

- Finochietto retractor
- One bone cutter
- One pair of long scissors
- Two vascular clamps
- Two hemostats
- Suture scissors
- One long Russian forceps
- Scalpel
- Two Duval lung forceps

Fig. 17.1 Equipment for the resuscitative thoracotomy. (**a**) Finochietto retractor. (**b**) Bone cutters. (**c**) Long pair of scissors. (**d**) Vascular clamps. (**e**) Hemostats. (**f**) Needle driver. (**g**) Short suture scissors. (**h**) Long Russian forceps. (**i**) Scalpel. (**j**) Duval clamps

17.4 Positioning

- Patient should be positioned supine with the left arm abducted at least 90° or greater above the head. Betadine antiseptic skin preparation should be performed prior to the start of the incision. However, rapid entry into the chest should be the priority and not be delayed. The release of tamponade and control of hemorrhage override the need for meticulous sterility in the emergency cases of a resuscitative thoracotomy. Additionally with surgical procedures, draping should be considered but not required in this particular procedure, as it is time-consuming and prevents an overall broad view of the anatomy and patient's critical condition.

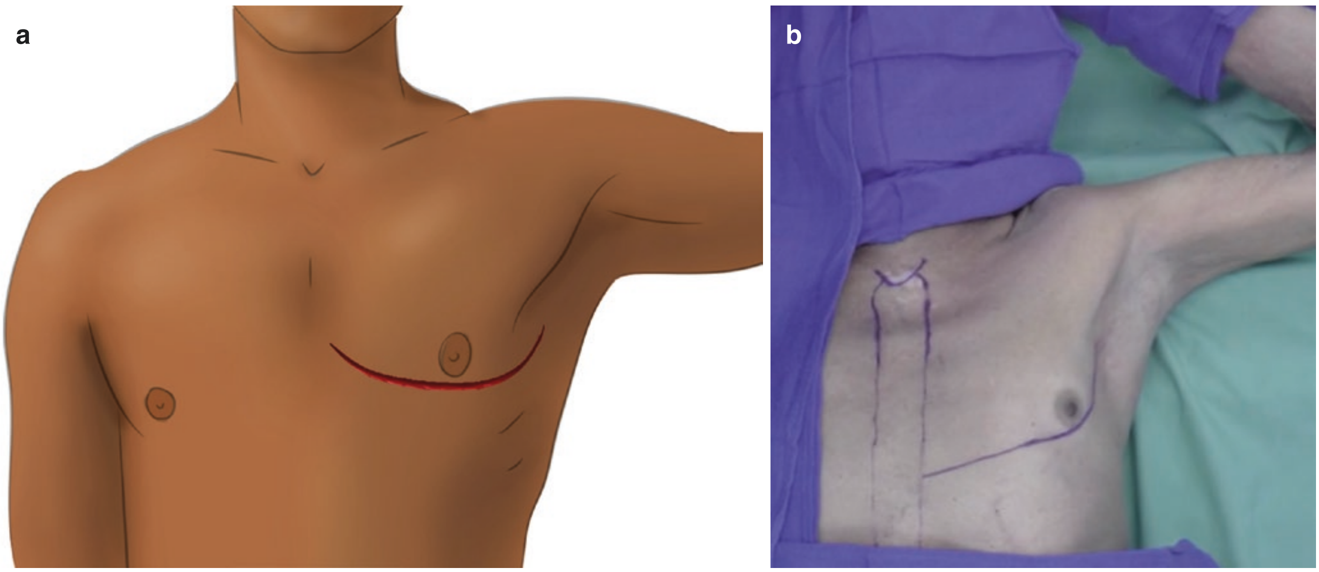


Fig. 17.2 (**a**, **b**) The patient's left arm abducted at least 90°. The incision made through the fourth or fifth intercostal space, just below the nipple in males and inframammary fold in females. It starts at the parasternal border and ends at the posterior axillary line, curving toward the apex of the axilla

17.5 Incision

- The resuscitative thoracotomy incision is made through the fourth or fifth intercostal space, just below the nipple in males and inframammary fold in females. It starts at the parasternal border and ends at the posterior axillary line. It should follow the curve of the ribs toward the apex of the axilla. The pectoralis major and pectoralis minor muscles anteriorly and the serratus anterior muscle posterolaterally are encountered and divided.
- The thoracic cavity is entered by dividing the intercostal muscles, close to the superior border of the rib in order to avoid injury to the neurovascular bundle, which is located at the inferior border of the rib. The pleural cavity is then entered with scissors taking care to avoid injury to the underlying lung. During entry into the cavity, the ventilation should be held to reduce the risk of injury to the underlying lung.

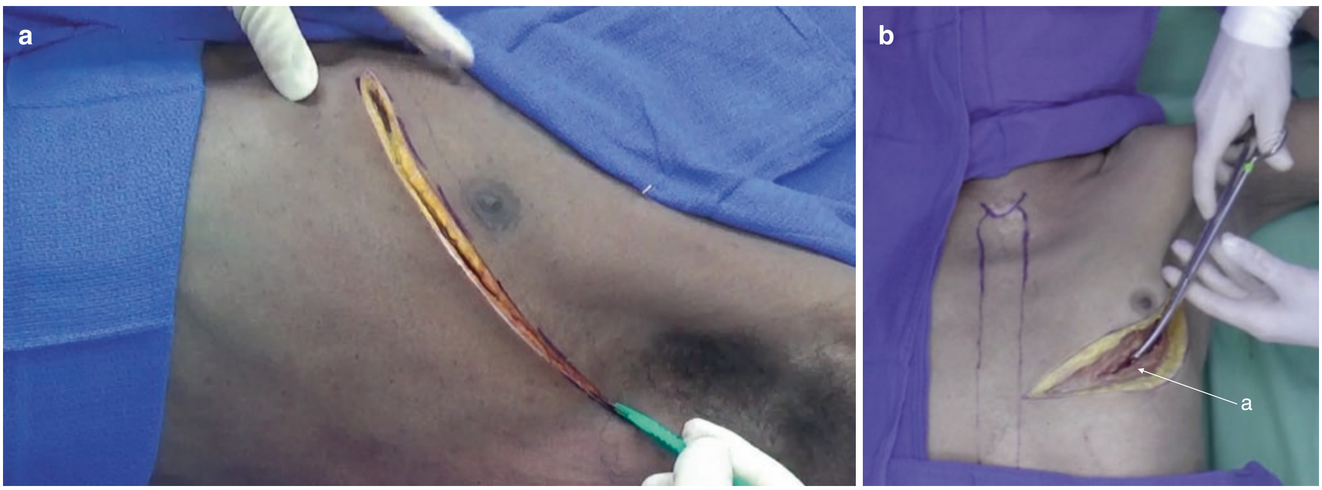


Fig. 17.3 (**a**) The incision should start at the parasternal border and extend to the left axilla at appropriately the fourth or fifth intercostal space. (**b**). The thoracic cavity is entered with scissors, close to the superior border of the rib, taking care to avoid injury to the underlying lung

17.6 Exposure

- A Finochietto retractor is then inserted between the ribs, and the handle on the Finochietto is turned counterclockwise to open the retractor jaws, spreading the ribs. It is helpful to have suction set up to help evacuate blood and clot that accumulate in the chest cavity. Duval forceps are used to grasp the left lower lobe of the lung, which is retracted toward the patient's head and laterally to improve the exposure of the heart and thoracic aorta.
- After entering the left pleural cavity, blood clot and free blood are quickly evacuated manually. Any obvious source of significant bleeding from the lung or thoracic vessels is controlled with direct pressure and vascular clamp if needed.
- The next step is to open the pericardium with a longitudinal incision on the lateral aspect and parallel to the phrenic nerve. In the absence of tamponade, the pericardium is grasped with two hemostats, and a small incision is made anterior to the phrenic nerve. However, in the case of tamponade, the pericardium is tense and difficult to grasp with a hemostat. In this case a small pericardiotomy is made with a scalpel and then the pericardium is opened longitudinally and parallel to the phrenic nerve. The pericardium is then opened in a cephalad and caudal direction to fully deliver the heart from the pericardium.

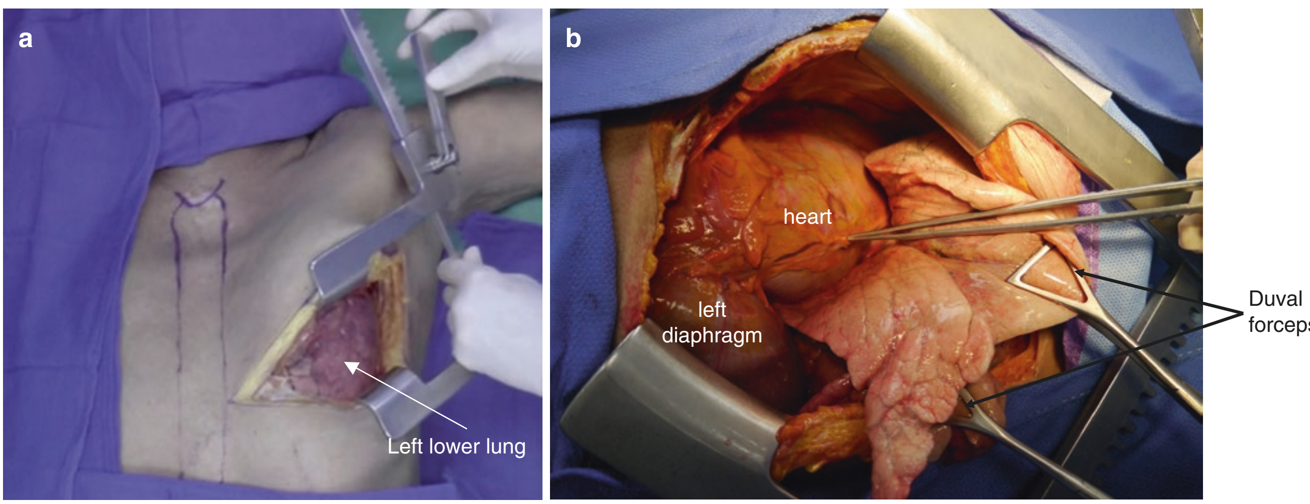


Fig. 17.4 (**a**) The Finochietto retractor is placed in the rib space and opened to expose the contents of the left thoracic cavity. (**b**) Duval forceps are used to grasp the left lower lobe of the lung, which is retracted toward the patient's head to improve the exposure of the heart and thoracic aorta

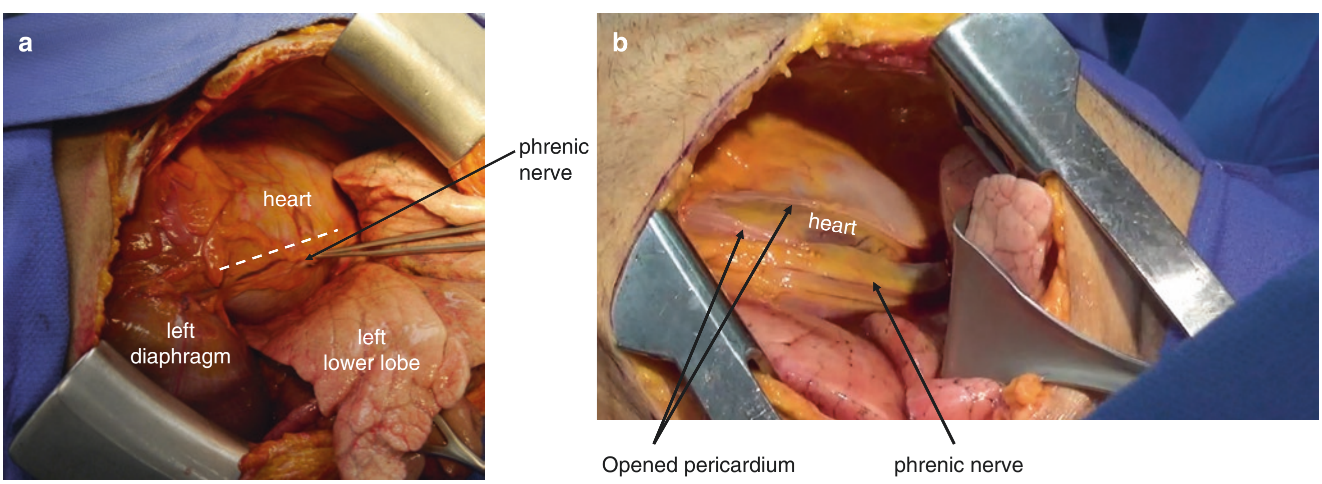


Fig. 17.5 (**a**) The pericardium is opened (interrupted line) longitudinally and parallel to the phrenic nerve. (**b**) The pericardium is opened longitudinally and the heart is exposed

17.7 Open Cardiac Massage and Defibrillation

- Open cardiac massage yields a much higher cardiac output when compared with external compressions. Cardiac compressions should be performed using both hands. The heart should be held between the two palms and compression from apex to the base of the heart. Compression using only one hand is not as ineffective and may actually cause cardiac perforation with the thumb.
- Irrigation of the heart with warm saline during open cardiac massage may help with the return of the cardiac function.
- Internal cardiac defibrillation should be used after resuscitative thoracotomy in cases with ventricular fibrillation or pulseless ventricular tachycardia. After the resuscitative thoracotomy is performed, cardiac massage is paused and the two internal cardiac paddles are placed on the anterior and posterior walls of the heart. The heart is then shocked with 10–50 J. Expeditiously after shocking, cardiac massage should be restarted without delay.

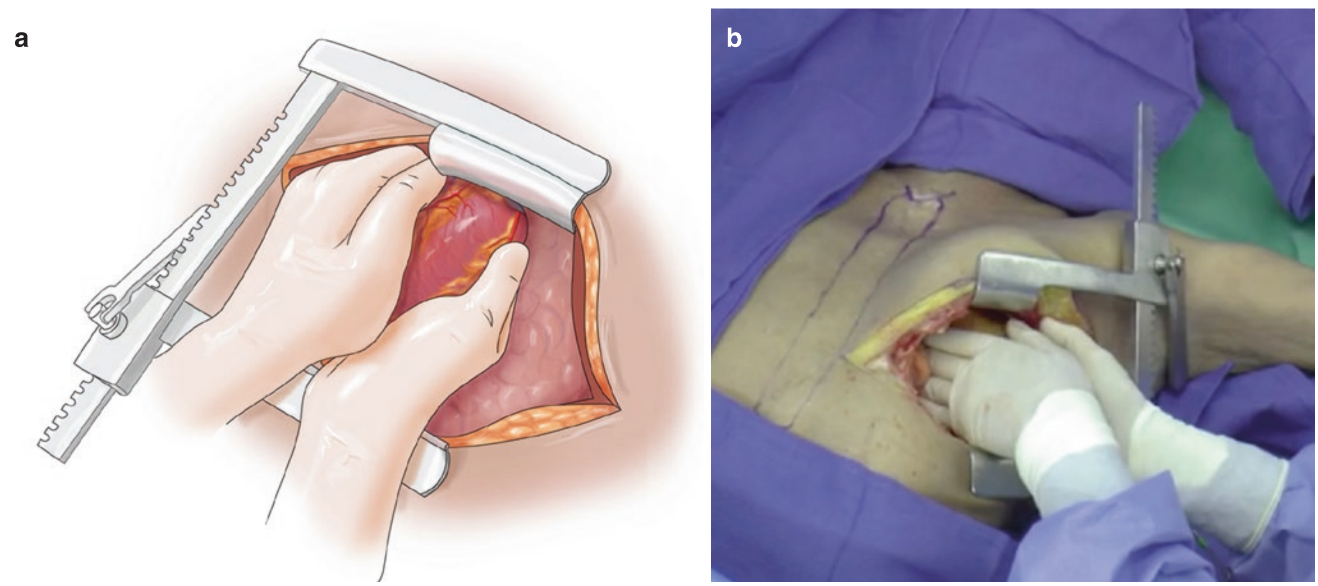


Fig. 17.6 (**a**, **b**) Cardiac compressions should be performed using both hands. The heart should be held between the two palms and compression from apex to the base of the heart

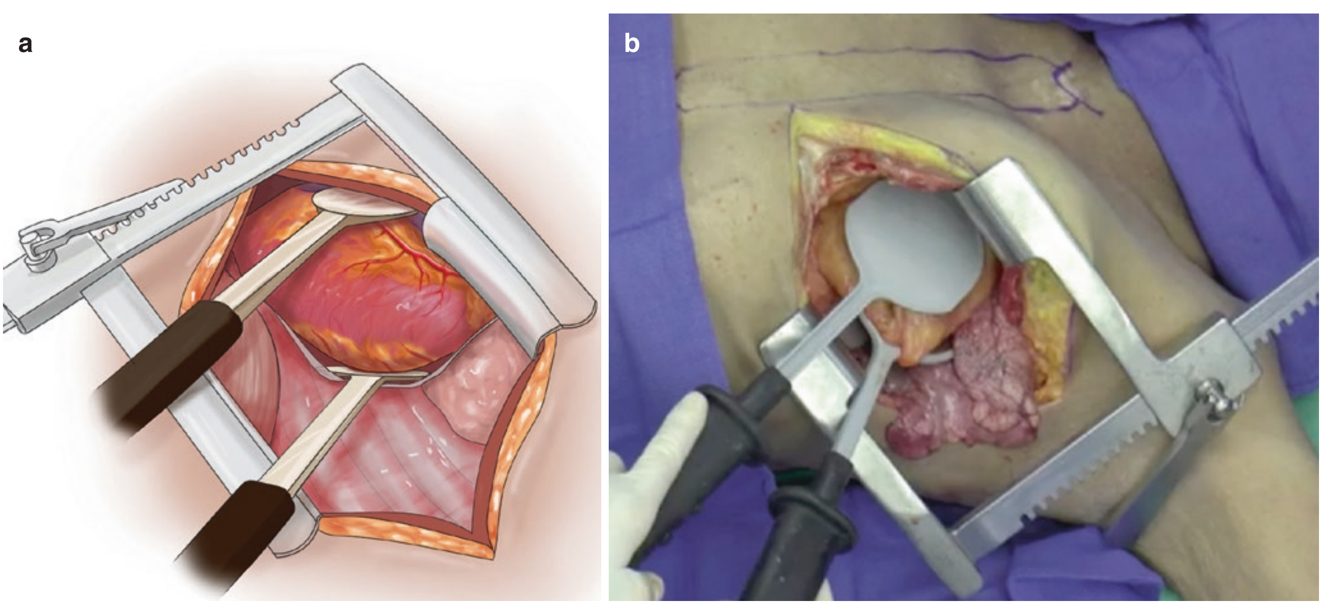


Fig. 17.7 (**a**, **b**) Internal defibrillation: the two internal cardiac paddles are placed on the anterior and posterior wall of the heart, and the heart is shocked with 10–50 J

17.8 Pharmacological Interventions

- Access to the left ventricle is made more technically accessible after a resuscitative thoracotomy. Medications can be injected directly into the left ventricle. Most commonly used medications are epinephrine, calcium, and magnesium.

Fig. 17.8 Resuscitative medications can be injected directly into the left ventricle

17.9 Epicardial Pacing

- Intraoperative and early postoperative temporary epicardial pacing should be considered in patients with arrhythmias.
- Two epicardial pacing wires are usually placed on the upper part of the anterior wall of the right ventricle. One is placed at the top of the ventricle and the second approximately 1 cm below on the right ventricle. Alternatively, the pericardial pacing wires can be placed on the left ventricle.
- On the epicardial pacing wire, the end has a small needle. The small needle is used to embed the pacing wire superficially into the myocardium. After the pacing wire is embedded, the needle is then cut off. Sometimes wires are slightly coiled to prevent easy dislodgment. A larger needle on the other end of the pacing wire is used to penetrate the chest wall and bring out to the skin surface. After the wires are exteriorized, they are connected to the pacer. The usual settings for the pacer are set for a heart rate of 70–90 beat per minute and a maximal current output of 10 mA.

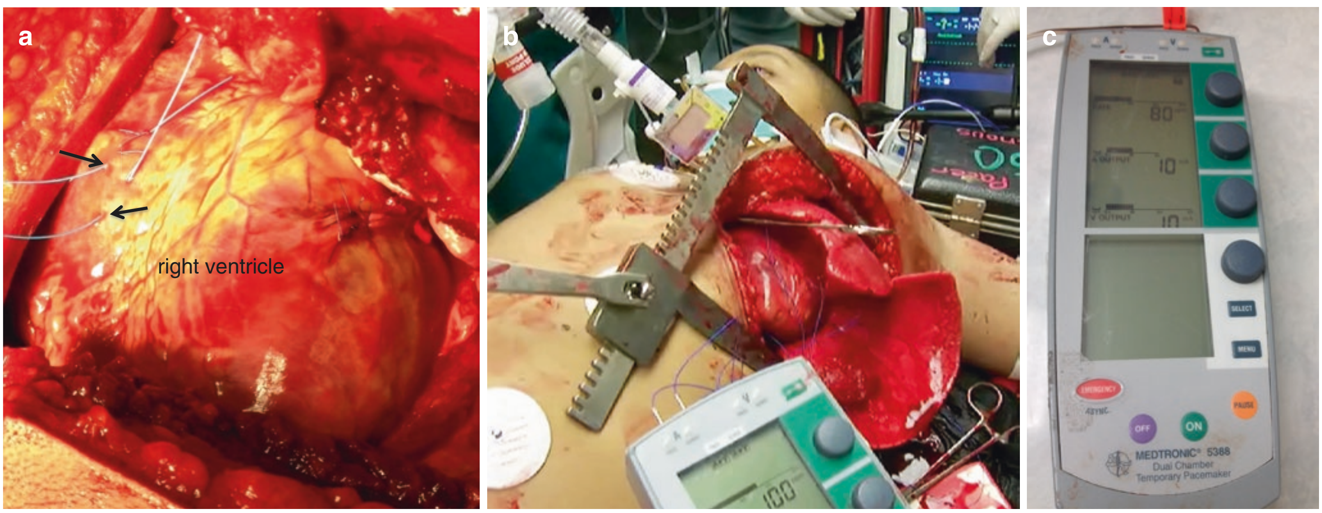


Fig. 17.9 (**a**) Two epicardial pacing wires (black arrows) are placed in the epicardium of the right ventricle, about 1 cm apart. (**b**) The pacing wires are connected to the pacer. (**c**) The usual settings for the pacer are set for a heart rate of 70–90 beat per minute and a maximal current output of 10 mA

17.10 Aortic Cross Clamping

- The most accessible site for aortic cross clamping in the chest is appropriately 2–4 cm above the diaphragm. After the left chest is retracted open with the Finochietto retractor, the left lower lobe is grasped with a Duval clamp and retracted cephalad and laterally, to expose the thoracic aorta. The inferior pulmonary ligament may be divided to provide further exposure. If the patient is in cardiac arrest, the aorta is collapsed and may be difficult to distinguish from the esophagus. A nasogastric tube should be inserted, if possible, to help identify and isolate the aorta for cross clamping. The aorta is the first structure felt while sliding your fingers along the posterior thoracic wall toward the spine. The mediastinal pleura over the aorta is opened sharply with scissors, and the index finger encircles the aorta. Minimizing the dissection around the aorta is important to prevent avulsion of the intercostal arteries, which could result persistent bleeding. A vascular clamp is then used to cross clamp the aorta. Removal of the aorta clamp should be removed when cardiac activity returns, usually within 30 min of its application.

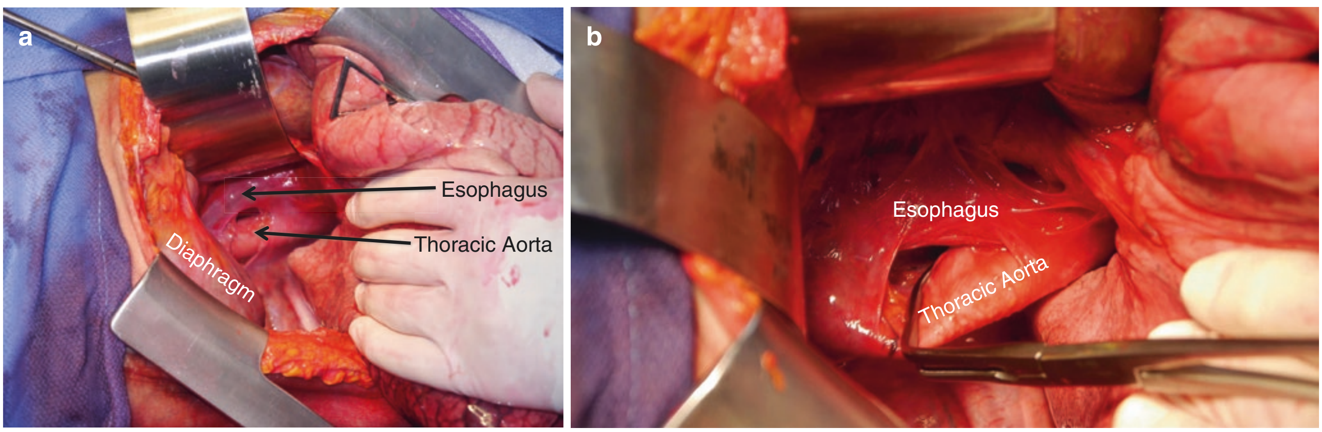


Fig. 17.10 (**a**) The mediastinal pleura over the aorta is opened sharply with scissors, and the aorta is identified. The esophagus is to the right and anterior to the aorta. (**b**) The aorta is cross clamped with a vascular clamp

17.11 Air Embolism

- In patients with cardiac arrest or severe arrhythmias who have injuries to low pressure cardiac chambers, the lung, or major veins, air embolism should be a suspected diagnosis. Oftentimes air bubbles can be visualized in the coronary veins. In these cases, controlling the source of air embolism should the primary concern, then followed by needle aspiration of air from the ventricles.

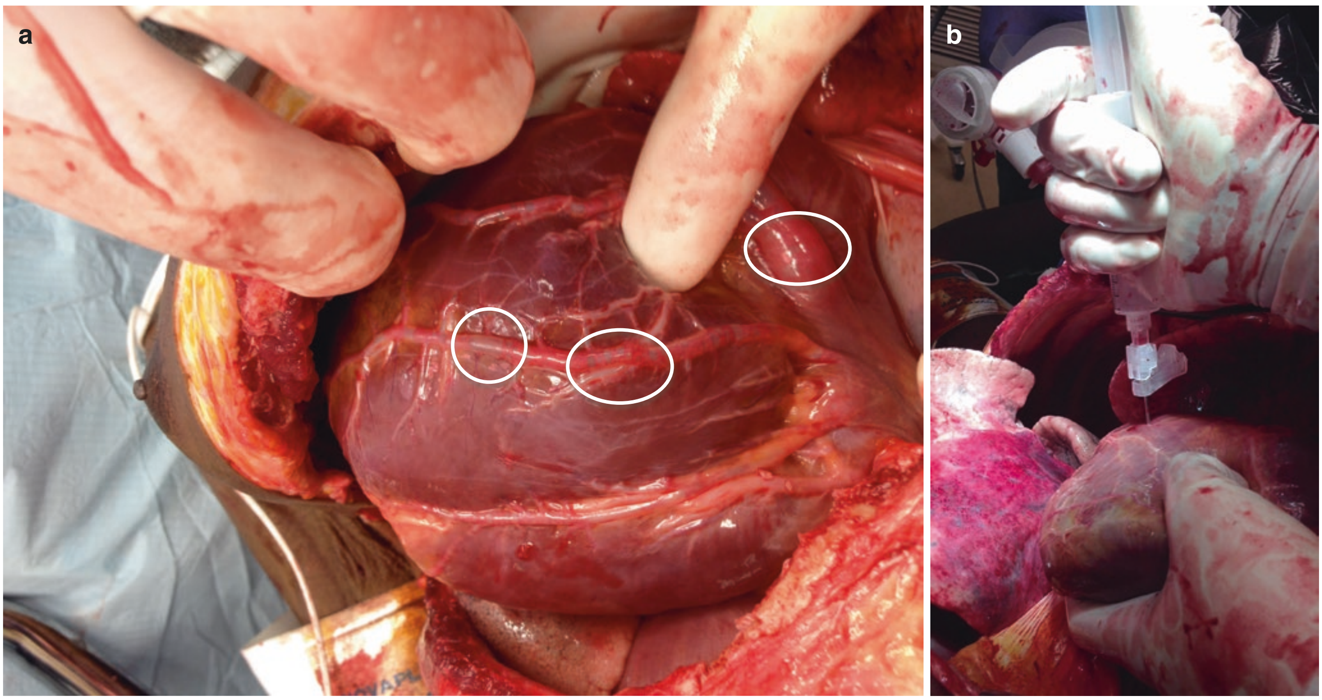


Fig. 17.11 (**a**) Air embolism: air bubbles can be visualized in the coronary veins (*circles*). (**b**) Needle aspiration of air from the ventricles for air embolism

17.12 Incision Closure

- The resuscitative thoracotomy, when used in the ICU, usually is followed up by interventional radiology or operative intervention. The chest wall is temporarily closed with plans to return for definitive closure when appropriate. Temporary closure is best performed with wet towels covered with a transparent adhesive dressing or VAC negative pressure dressing, with low suction settings. The temporary closure is quick and allows easy access to the chest cavity if needed for recurrent cardiac arrest.
- If the patient stabilizes, definitive formal closure of the chest wall should be performed in the operating room.

Fig. 17.12 Temporary closure of the thoracotomy incision can be performed with wet towels covered with a transparent adhesive dressing or VAC negative pressure dressing, with low suction settings

17.13 Tips and Pitfalls

- Low placement of the anterolateral incision increases the risk of iatrogenic injury to the diaphragm. In addition, a low incision provides a poor exposure of the heart and makes it technically difficult for cardiac massage.
- Failure to follow the curve of the ribs makes the incision and entry into the pleural cavity difficult and messy. To avoid this problem, direct the incision toward the axilla.
- Division of the intercostal muscles with the scalpel, especially if the ventilation of the lung is not paused, may result in injury to the underlying lung. Use scissors and hold the ventilation during the entry into the chest cavity.
- The internal mammary artery may be injured if the thoracotomy starts very close to the sternum. The bleeding may not be obvious if the patient is severely hypotensive, and if not recognized and ligated, it might bleed profusely later on when the blood pressure rises.
- During cross clamping of the aorta, the physician may inadvertently place the clamp on the esophagus. The esophagus is located anteromedial of the aorta. A nasogastric tube can help to identify the esophagus. In a hypovolemic patient, the aorta is collapsed and often not pulsatile and makes its identification difficult. In these situations, slide the fingers of the right hand along the posterior thoracic wall toward the spine, and the first structure felt is the aorta.

Intra-Aortic Balloon Pump Insertion and Management

18

Fernando Fleischman and John David Cleveland

18.1 General Principles

- Intra-aortic balloon pump (IABP) counterpulsation is a useful circulatory support adjunct in the setting of refractory cardiogenic shock in critically ill patients. The IABP increases myocardial oxygen perfusion and increases the cardiac output.
- The IABP inflates in diastole, increasing blood flow to the coronary arteries. It deflates in systole decreasing afterload (Fig. 18.1).
- Indications for placement include coronary ischemia, acute mitral regurgitation, severe myocardial contusion, and cardiomyopathy (of multiple etiologies) resulting in refractory cardiogenic shock despite adequate vasopressor support.
- Absolute contraindications include existing aortic injury (i.e., dissection) or severe aortic insufficiency.
- Site of insertion is primarily the common femoral artery although axillary/subclavian and direct aortic arterial access are feasible.
- Weaning IABP should be performed with the aid of a method to assess cardiac function in addition to systemic blood pressure.

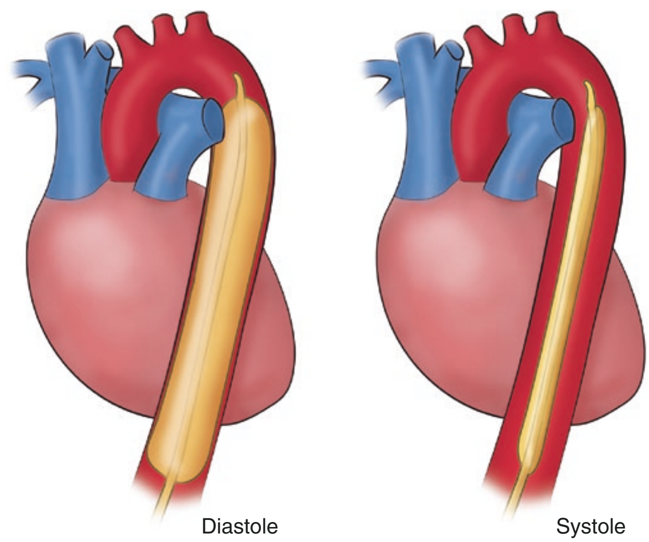


Fig. 18.1 The IABP inflates in diastole and deflates in systole

F. Fleischman (✉) · J. D. Cleveland
Department of Cardiothoracic Surgery, USC, School of Medicine, Los Angeles, CA, USA
e-mail: Fernando.fleischman@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_18

18.2 Function

- Balloon inflates during diastole either timed by the electrocardiogram or pressure measurements (Fig. 18.2).
- Inflation during diastole displaces blood back toward the aortic valve and forward to abdominal viscera. When it deflates at the onset of systole, the aorta is less pressurized with blood.
- The result is increased myocardial oxygen delivery, decreased left ventricular afterload, increased coronary perfusion pressure, and ultimately increased cardiac output.

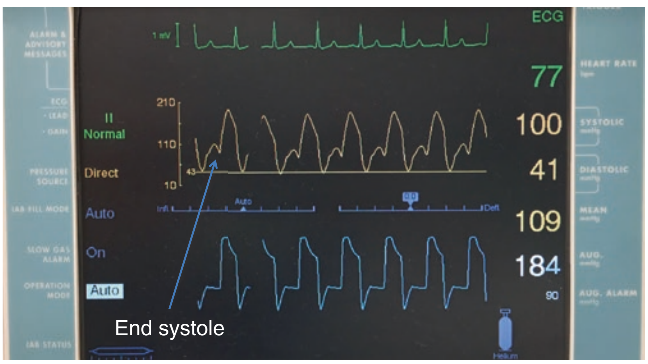


Fig. 18.2 Example of arterial tracing as displayed on IABP console. Following each QRS, there is a systolic upstroke in blood pressure followed by a short fall at the end of systole. A larger upstroke follows during diastole during balloon inflation demonstrating a large augmentation in pressure

18.3 Necessary Equipment

Disposable

- Antiseptic skin prep.
- One percent lidocaine, 10 cc syringe, 25 gauge needle.
- Sterile towels or central line drape.
- #11 blade sterile scalpel.
- Sterile ultrasound probe cover.
- All IABP system components: 18 gauge introducer needle, 0.025 in. guidewire, dilator, 7–9 French sheath, balloon, gas tubing, three-way stopcock, and arterial pressure tubing (Fig. 18.3a, b).

Non-disposable

- Ultrasound (preferred).
- Fluoroscopy or transesophageal echocardiography (if available).
- Balloon pump.

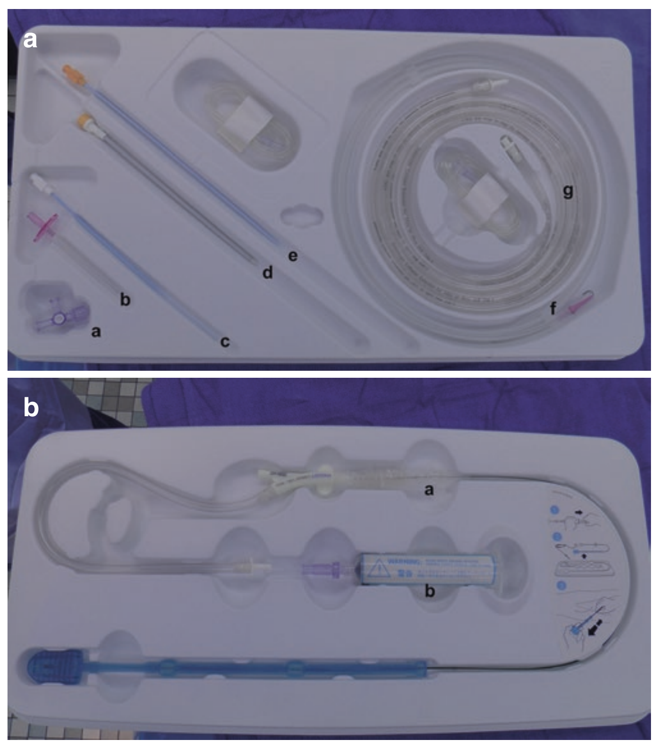


Fig. 18.3 (**a**) IABP components part 1: (*a*) three-way stopcock, (*b*) 18 gauge introducer needle, (*c*) dilator, (*d*) 7–9 French sheath, (*e*) sheath dilator, (*f*) guidewire, (*g*) gas pressure tubing. (**b**) IABP components part 2: (*a*) intra-aortic balloon (*b*) de-airing syringe

18.4 Positioning and Site of Insertion

- Patient should be supine without any hip flexion. Trendelenburg or reverse Trendelenburg positioning is unnecessary.
- The common femoral artery should be identified either by palpation based on the location of the inguinal ligament (Fig. 18.4) or directly by use of ultrasound identification of the take-off of the profunda femoris artery.
- If axillary, subclavian, or direct aortic access is necessary due to femoral arterial injury or occlusive peripheral vascular disease, recommend consultation with a cardiologist or cardiac surgeon for insertion.

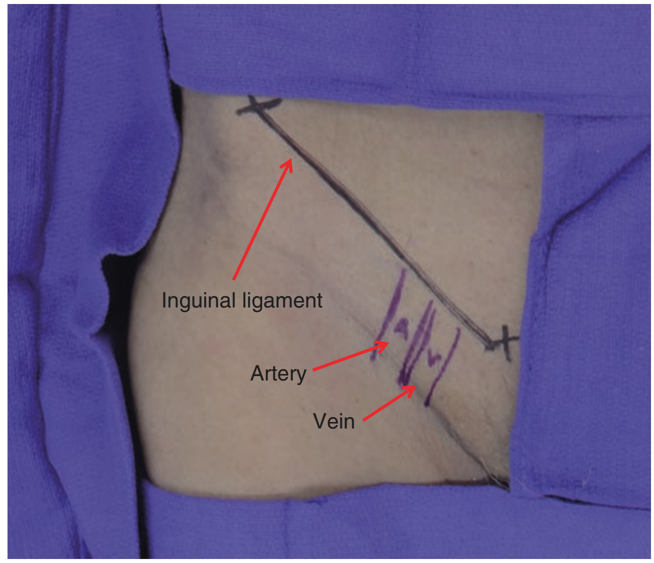


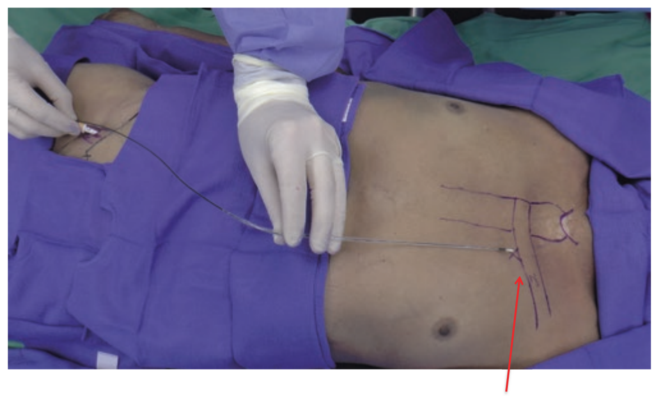
Fig. 18.4 Groin anatomy with line marking location of the inguinal ligament running in between the anterior superior iliac spine and pubic tubercle (denoted by Xs). Course of artery (A) and vein (V) marked

18.5 Placement

- Balloon size is chosen prior to insertion in order to avoid left subclavian, mesenteric, and/or renal artery obstruction (see chart).

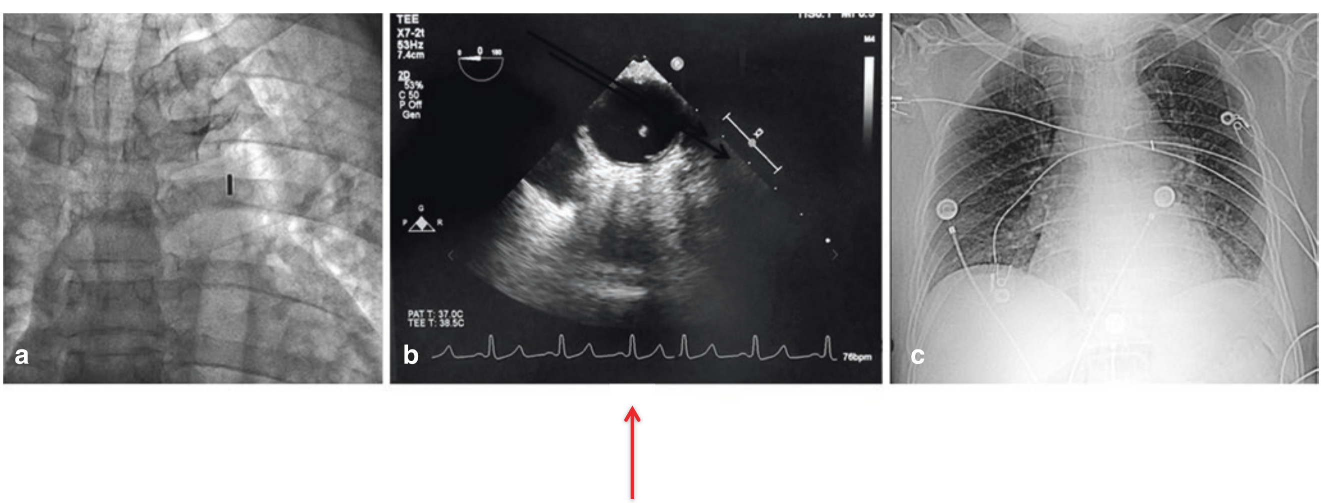
Patient height (cm)	IABP volume (cc)	Body surface area (m^2)
4′10″–5′4″ (147–162)	30	Less than 1.8
5′4″–6′0″ (162–182)	40	Greater than 1.8
>6′0″ (182)	50	Greater than 1.8

- The balloon should be prepared prior to insertion by aspirating all air from the balloon with vacuum. Do not remove from tray until ready for intracorporeal insertion.
- The dilator should be placed through the sheath in preparation for insertion.
- After identifying the common femoral artery, anesthetize the overlying skin and subcutaneous layer with local anesthetic in the awake patient.
- Introducer needle should then be placed into the CFA either via palpation or ultrasound guidance. Position is confirmed by brisk pulsatile bright red bleeding. If the blood is dark or flow is sluggish, concern should be for venous misplacement. Recommend removal of the needle, pressure at the site of insertion, and reattempt after hemostasis is obtained.
- Once successful femoral arterial needle cannulation is obtained, the guide wire should be advanced through the needle into the descending thoracic aorta. This should leave approximately 24 in. of wire outside the body. Do not advance the guidewire if any resistance is encountered at any time.
- The balloon can be placed directly through the skin or through the sheath.
- If the sheath is desired, make a small skin incision with 11 blade scalpel around the wire with a knife and advance the sheath smoothly into the artery.
- Estimate the course of the IABP and plan for the tip to terminate in the second intercostal space (Fig. 18.5).
- Advance the balloon over the wire into place and confirm placement.
- Tip should be positioned just distal to left subclavian artery and confirmed by fluoroscopy or transesophageal echocardiogram at this time. However, if these modalities are not available, chest X-ray can be used for delayed confirmation (Fig. 18.6).
- Aspirate blood from the lumen of the balloon, connect to arterial pressure tubing, and flush system free of air.
- Connect gas tubing to pump and initiate therapy at 1:1 timing with full augmentation.
- Secure sheath and IABP to skin with suture or Stat Locks.



Clavicle

Fig. 18.5 Demonstration of gross estimation of balloon location with goal of tip terminating at the second intercostal space (X)



Echo guidance

Fig. 18.6 Examples of the three methods of confirmation of balloon placement: (**a**) fluoroscopy, (**b**) transesophageal echocardiography (green arrow denotes takeoff of left subclavian artery from aorta), (**c**) chest X-ray. The blue arrow marks the tip of each balloon

18.6 Management

- The balloon is set to inflate immediately after aortic valve closure (indicated by the dicrotic notch on arterial pressure tracing) and deflate immediately prior to aortic valve opening (just prior to arterial waveform upstroke).
- The inflation trigger can be based on electrocardiogram (EKG) or pressure. If the patient is having persistent arrhythmias, pressure triggering may be preferable. Otherwise, EKG triggering is recommended. Adjustments can be made on the balloon console (Fig. 18.7).
- 1:1 inflation timing with full augmentation provides the maximal amount of support and should be utilized until patient status stabilized to point where IABP weaning feasible.
- Vasoactive drips should be weaned to acceptable levels in light of IABP assistance but should not be entirely ceased as it is preferable to wean and remove IABP first.
- Our group usually pursues anticoagulation with a small basal heparin infusion of 500 units/hr. not dosed to a specific activated partial thromboplastic time. However, the one randomized trial to determine the benefit of anticoagulation for IABPs failed to show any reduction in limb ischemia and did demonstrate a slight increase in bleeding. If the patient is at risk for bleeding, it is reasonable not to anticoagulate despite the presence of IABP.
- Potential complications should be continually monitored for and include: aortic injury (dissection or rupture), balloon rupture (helium embolus), limb ischemia, distal emboli, bleeding, and infection. Presence of these complications should prompt appropriate expert consultation and IABP removal as indicated.

Fig. 18.7 Control panel for the IABP

18.7 Removal

- Consider initiating IABP wean with onset of signs of myocardial recovery: ability to wean vasoactive drips, increase in cardiac output, improved ventricular function on echocardiogram, and no evidence of augmentation over systemic pressures on balloon tracing.
- The pump should be weaned progressively by frequency of balloon inflation from 1:1 to 1:2 and finally to 1:3 (if concern exists at 1:2). Ability to separate from support should be determined by the response in blood pressure and cardiac output as measured by Swan-Ganz catheter during weaning. Vasoactive drips should be adjusted as needed to maintain appropriate hemodynamics during this process.
- Once ready for removal, systemic anticoagulation should be held, pump function ceased, and the entire balloon and sheath removed together. Pressure should be applied manually by hand or a mechanically with a hemostatic device. Regular vascular assessment of the affected limb should proceed in the hours following removal.

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

19 Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

Chrissy Guidry and Elizabeth R. Benjamin

19.1 General Principles

- REBOA is an endovascular balloon system, which can be used in the emergency room, operating room, or intensive care unit, usually in trauma patients, for temporary bleeding control in the abdomen or pelvis (Fig. 19.1).
- The REBOA device is inserted using a transfemoral approach, and the balloon is inflated in the lower thoracic or abdominal aorta to establish temporary aortic occlusion and hemorrhage control, acting like an internal aortic cross-clamp.
- REBOA is used to bridge a patient to definitive treatment in the operating room or the interventional radiology suite.
- REBOA can be placed within a few minutes.
- REBOA is contraindicated in patients in cardiac arrest. In these cases a resuscitative thoracotomy with cross-clamp of the aorta and internal cardiac massage should be performed. The procedure is also contraindicated for intrathoracic bleeding and in cases with clinical or radiological suspicion of blunt thoracic aortic injury.
- REBOA produces distal ischemia and may cause ischemic damage to the kidneys, bowel, and liver if the occlusion is prolonged. Ideally, zone I occlusion should not last longer than 30 min.

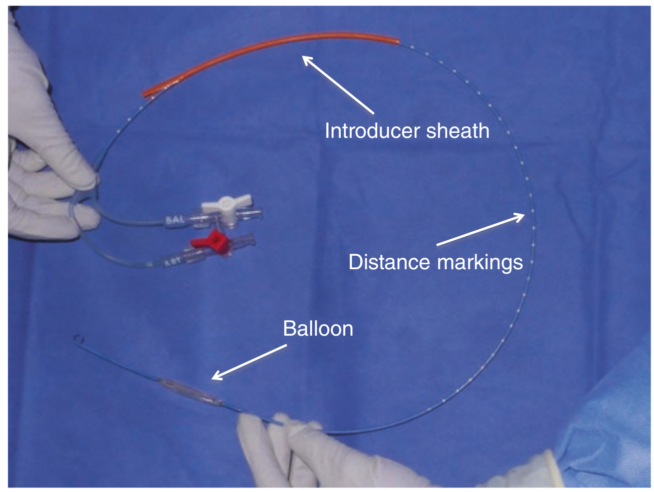


Fig. 19.1 The ER-REBOA catheter is a commercially available wireless REBOA catheter designed for used through a 7F sheath. There are balloon and arterial ports. It comes with an introducer sheath that is designed to straighten out the J-tip for easy entry into the arterial sheath. The markings on the catheter help to measure the distance for accurate placement

C. Guidry · E. R. Benjamin (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: Elizabeth.benjamin@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_19

19.2 Relevant Surgical Anatomy

- Placement of the REBOA requires access to the common femoral artery.
- The artery may be accessed percutaneously using ultrasound guidance or anatomic landmarks. An open approach may also be used.
- The aorta is divided into three anatomical zones for the purposes of REBOA insertion (Fig. 19.2):
  - Zone I
    Distal to the left subclavian artery, above the diaphragm.
    The external landmark for zone I is the mid sternum.
  - Zone II
    From the celiac artery to renal arteries (visceral vessels).
    Inflation of the aortic occlusion balloon is not recommended in zone II.
  - Zone III
    Distal to the renal arteries to above the aortic bifurcation.
    The renal arteries branch at the level of L1–L2.
    The aortic bifurcation occurs at the level of L4. The external landmark for the bifurcation is the umbilicus.
    Zone III is typically below L2 and above L4.

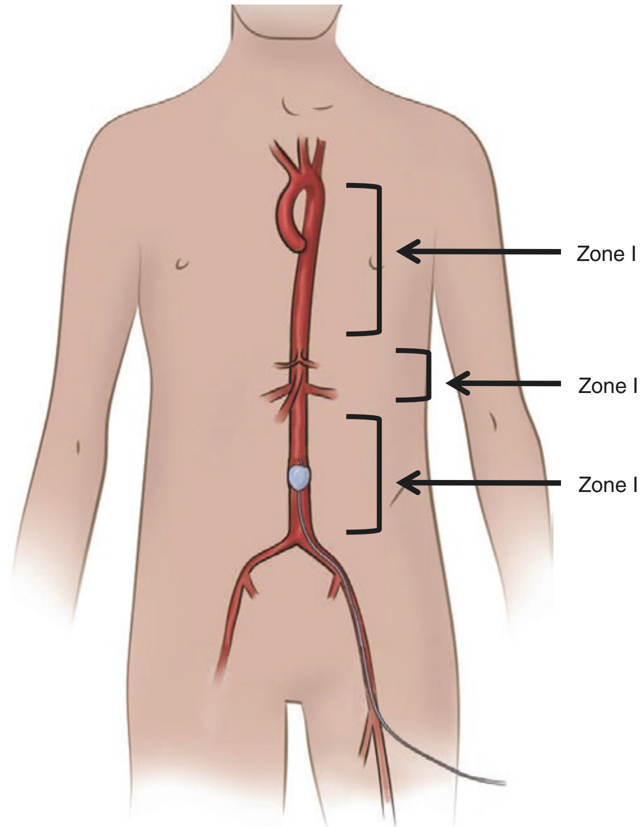


Fig. 19.2 For the purposes of REBOA, the aorta can be divided into three zones. Zone I includes the thoracic aorta distal to the subclavian artery, zone II is the mesenteric portion of the abdominal aorta, and zone III is from below the renal vessels to above the bifurcation

19.3 Preparation

- There are several commercially available REBOA devices. These devices vary in the additional components required. It is imperative to have the appropriate sized sheath in order to pass the catheter.
- Personal protective equipment (cap, gown, gloves, mask, eye protection)
- Arterial sheath kit
  - Access needle
  - Guidewire
  - Sheath (7F or larger, dependent upon catheter used)
- Ultrasound with vascular probe
- Scalpel
- REBOA catheter
- 20 cc syringe
- Three-way stopcock
- Sterile drape
- Suture material

19.4 Technique

- The patient should be placed in the supine position.
- The REBOA can be placed in either groin. The decision of laterality should be made based on provider preference and influenced by the desire to avoid traversing any known or suspected injuries. For a right-handed provider, the right common femoral artery is the most common access site.
- The groin is prepped and draped in the standard sterile fashion.
- Full protective gear should be worn.
- The common femoral artery is accessed percutaneously using anatomic landmarks or ultrasound guidance. The common femoral artery may also be accessed using a local open approach.
- The femoral artery is located approximately 2 cm below the inguinal ligament approximately halfway between the pubic symphysis and the anterior superior iliac crest.
- Access the common femoral artery using a needle angled in the cephalad direction.
- Using Seldinger technique, exchange the needle for a 7F arterial sheath (Fig. 19.3).
- Several aortic occlusion devices are commercially available. It is imperative that the provider is familiar with the institutional availability of these devices as some may require exchange for a larger sheath.
- Measure the REBOA from entry to the mid sternum. This will provide an external landmark for zone I occlusion (Fig. 19.4).
- Advance the REBOA catheter through the femoral artery to the desired location (Fig. 19.5).
  - If immediate X-ray capabilities are available, the REBOA may be inflated in zone I or zone III (Fig. 19.6).
  - If immediate X-ray capabilities are not available, the mid-sternal external landmark may be used to occlude the aorta in zone I. This is a reliable approach when X-ray is not available (Fig. 19.7).
- Inflate the REBOA balloon using the volume recommended per manufacturer's instruction. Some available devices have graded inflation volumes for variable balloon diameters.
- Note the time of aortic occlusion and proceed to definitive hemorrhage control.
- The balloon may be intermittently or partially deflated to identify distal bleeding sources.
- Note that, especially during deflation, the balloon may migrate and reinflation zone may change.

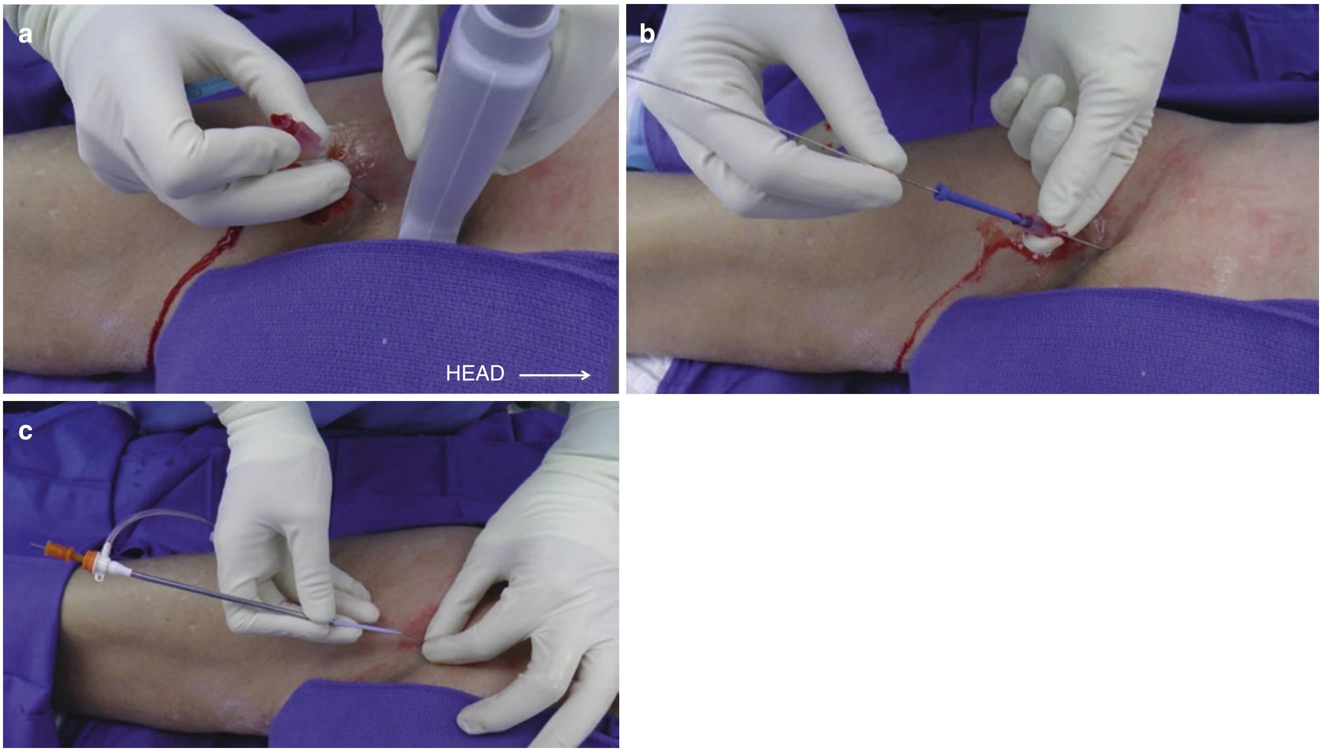


Fig. 19.3 The common femoral artery is accessed percutaneously with ultrasound guidance or using an open technique (**a**). An arterial sheath is placed using standard Seldinger technique (**b**, **c**). Confirm that the sheath size will accommodate the REBOA catheter to be used

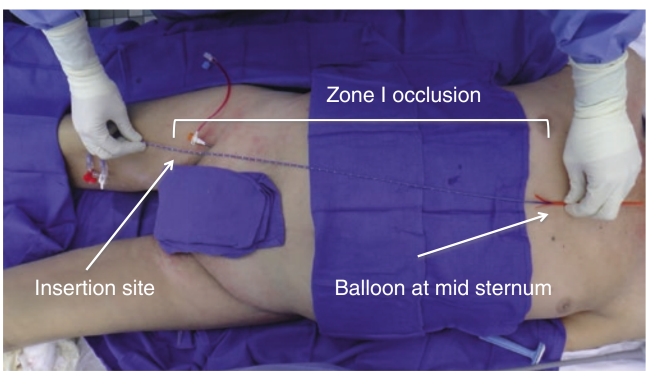


Fig. 19.4 Balloon landing site for zone I can be identified using imaging or external landmarks measuring the distance for the balloon to traverse from the entry site to the mid sternum

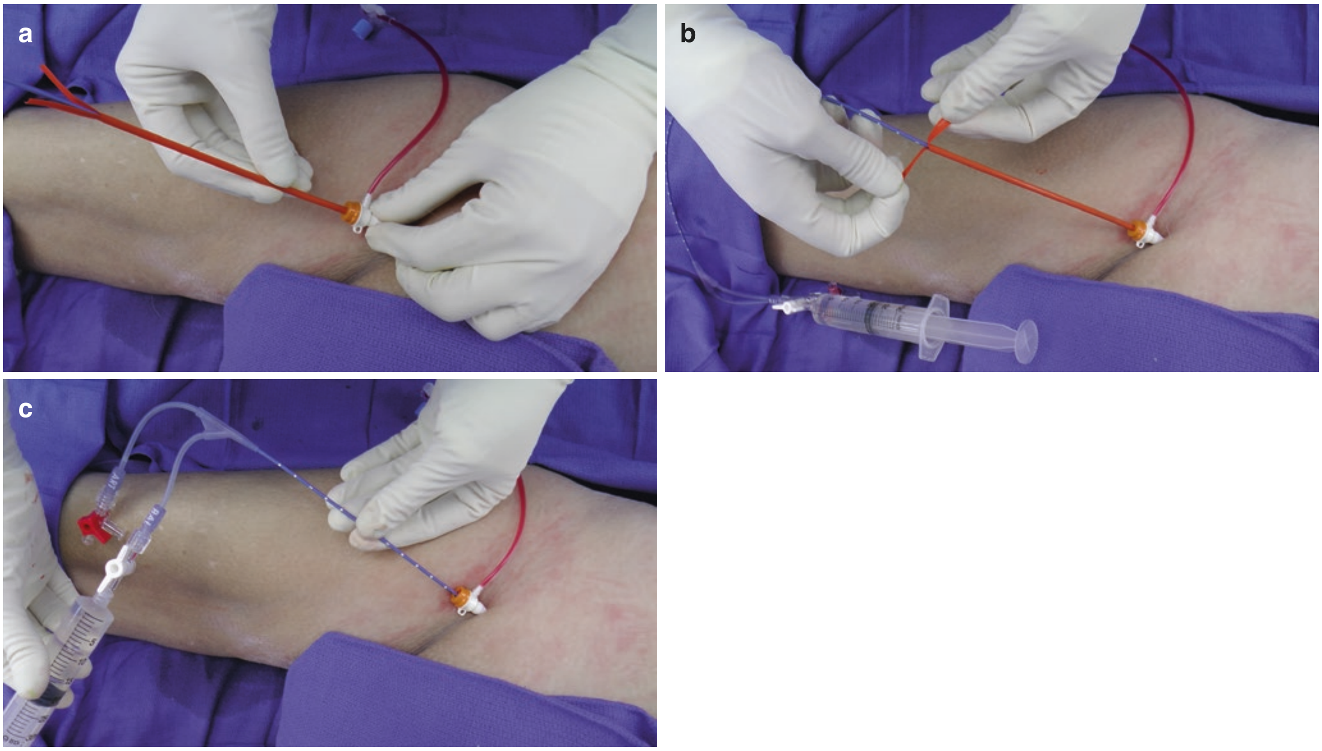


Fig. 19.5 For the ER-REBOA, place the provided peel away sheath over the tip and balloon of the REBOA catheter. Insert this peel away into the arterial sheath valve approximately 5 mm and advance the balloon into the artery (**a**). Once the balloon has passed through the arterial sheath valve, remove the peel away (**b**). Advance the REBOA catheter to the desired distance and inflate the balloon based on manufacturers recommendations (**c**)

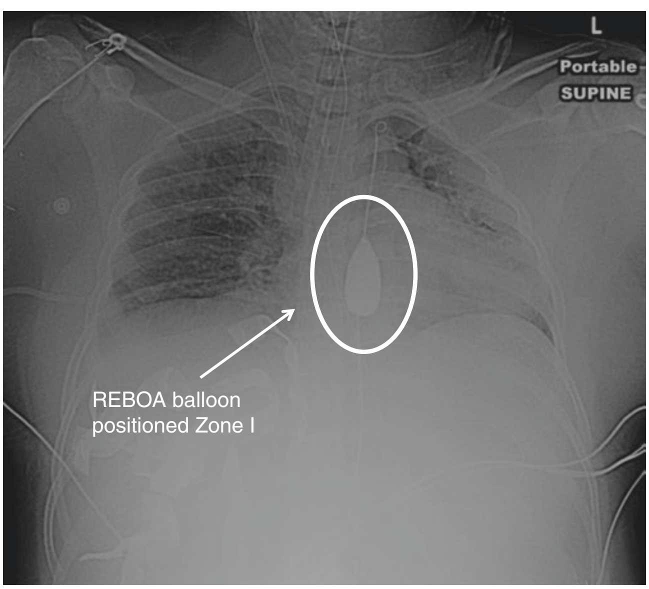


Fig. 19.6 If fluoroscopy or X-ray are being used to confirm placement, obtain imaging to confirm correct balloon position

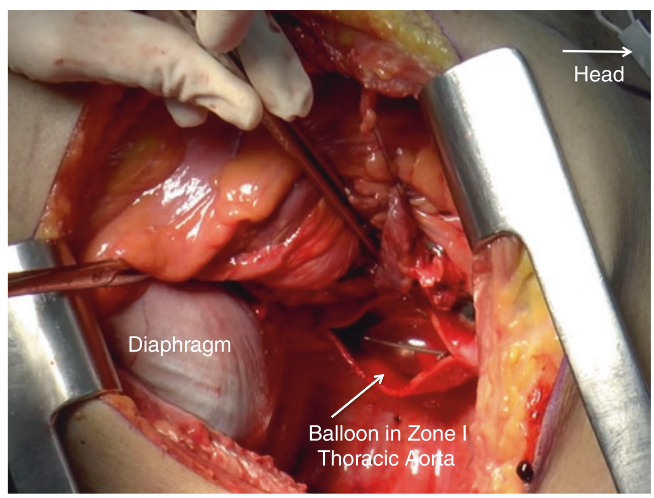


Fig. 19.7 Zone 1 placement of the REBOA balloon above the level of the diaphragm

19.5 Removal

- Fully deflate the REBOA balloon prior to removal.
- Continue frequent monitoring of distal pulses and muscle compartments.
- The arterial sheath should be removed as soon as clinically appropriate to minimize risk of arterial thrombosis or embolism.
- Smaller sheaths (7F) may usually be removed with compression for hemostasis. In coagulopathic patients, longer periods of compression may be required.
- Larger sheaths may require a percutaneous closure device or an open arterial exposure and repair for removal.
- Post removal ultrasound or operative exploration should be considered in patients with suspected pseudoaneurysm or arterial injury.

19.6 Complications

- REBOA inflation is designed to occlude blood flow distal to the level of inflation. For zone I inflation, occlusion can lead to visceral, renal, and lower extremity ischemia.
- Complications can include bowel ischemia, reperfusion injury, acute kidney injury, distal embolism, and extremity compartment syndrome requiring fasciotomy.
- Although less common with the smaller profile catheters, local complications can occur at the sheath insertion site including dissection, false aneurysm, transection, and thrombosis.

19.7 Tips and Pitfalls

- Knowledge of femoral anatomy is critical for safe and effective placement of the REBOA. Often the patient has only a weakly palpable femoral pulse and anatomic landmarks, or ultrasound is needed to safely access the common femoral artery.
- Access to the common femoral artery should be just below the level of the inguinal ligament. A common pitfall is distal access resulting in placement of the arterial sheath in the superficial femoral artery. This can lead to critical limb ischemia and potential limb loss.
- Arterial injury or transection can occur with sheath placement. It is imperative to perform frequent vascular checks distal to the catheter and early catheter removal is key.
- Dependent upon size used, the sheath may need to be removed under direct visualization. The provider should be prepared to perform an embolectomy, arterial repair, or bypass in the event of arterial injury.
- The thigh and lower leg should be monitored closely for compartment syndrome with a low threshold for performing fasciotomies.
- Familiarize yourself with the device available at your institution. Sheath size and inflation volumes vary significantly between commercially available catheters.
- Balloon inflation should cease once resistance is encountered. Overinflation can lead to balloon rupture or arterial wall injury (Fig. 19.8).
- All components needed to place a REBOA, including extra sheaths, should be stored in close proximity to the catheter.
- REBOA is a temporary occlusion device and is designed as a bridge to definitive management. Patients should continue to receive appropriate resuscitation and be transitioned to the operating room or interventional radiology suite for definitive hemorrhage control.

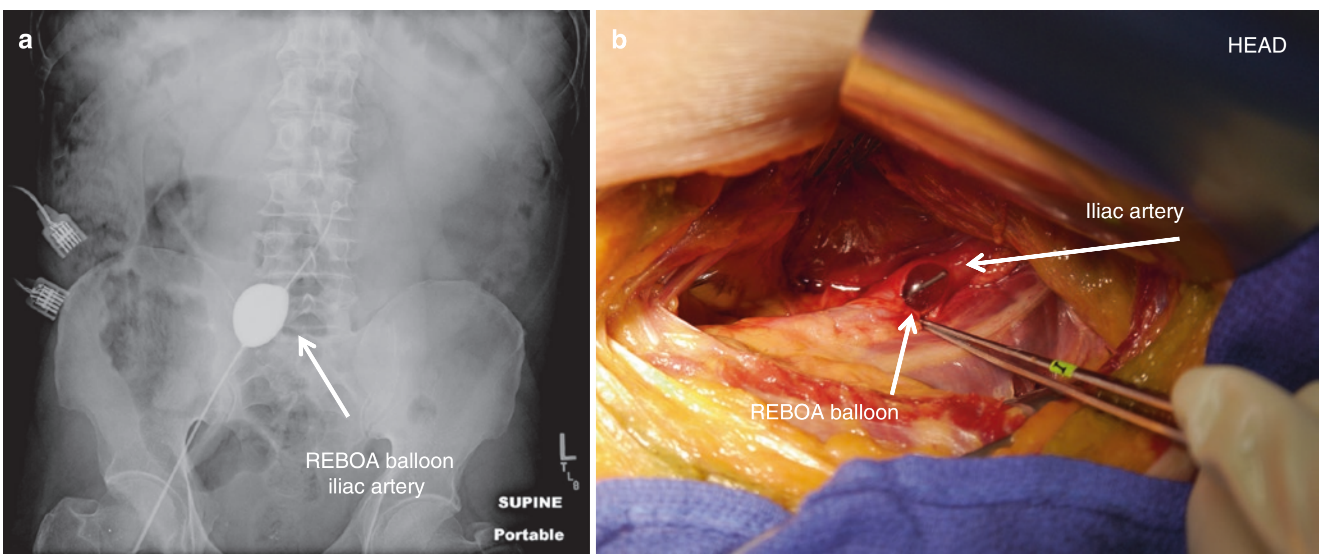


Fig. 19.8 Correct placement and appropriate inflation of the REBOA balloon in essential to avoid iatrogenic injuries. Abdominal X-ray of a patient with an overexpanded REBOA balloon, inflated in the iliac artery (**a**). Retroperitoneal exposure of the iliac artery with an arterial laceration at the site of a REBOA balloon (**b**)

20 Temporary Transvenous Cardiac Pacing

Aaron Strumwasser and Brad Allen

20.1 Surgical Anatomy

- For detailed descriptions of the anatomy of the neck, please refer to Surgical Anatomy chapters on *Central Venous Access and Pulmonary Artery Catheterization*.

20.2 General Principles

- Consent from the patient or family member should be obtained whenever possible. Risks include:
  (a) Arterial puncture
  (b) Pneumothorax
  (c) Infection
  (d) Bleeding
  (e) Venous obstruction or thrombosis
  (f) Air embolism
  (g) Cardiac perforation
  (h) Cardiac tamponade
  (i) Pulmonary embolism
  (j) Cardiac arrhythmias
- Elective procedures should be done under sterile precautions, including body draping, gown, mask, and sterile gloves. Skin disinfection with chlorhexidine is superior to alcohol or iodine-based solutions. Cover the skin entry site with dry gauze or transparent breathable dressing. When ultrasound is used, the probe should be covered with a sterile probe cover.
- Catheters placed emergently, under suboptimal sterility, should be removed or replaced within 24 h.

20.3 Indications

- Temporary transvenous pacing is indicated for symptomatic bradyarrhythmia or bradyarrhythmia associated with hemodynamic impairment that occurs from an acute event. These include sinus arrest, sinus bradycardia, symptomatic second-degree block (Mobitz type II), and third-degree block.
- These indications assume less invasive means (pharmacologic agents) have been unsuccessful, and the patient is experiencing significant symptomatology (chest pain, altered level of consciousness, dyspnea, shock, hypotension, pulmonary edema, acute myocardial infarction).
- A temporary pacemaker may also be indicated to treat a supraventricular tachycardia refractory to medical management with overdrive pacing or to increase the heart rate (improve cardiac output) in patients in cardiac failure.
- Temporary transvenous pacing is indicated when dysrhythmia can cause significant deterioration, and there is no time to place a permanent pacemaker.
- Temporary transvenous pacing is used as a bridge to permanent pacing for conditions where prolonged pacing is indicated (second- or third-degree atrioventricular (AV) nodal block or bundle branch block).
- Temporary transvenous pacing is indicated when there is unclear indications for permanent pacing in a hemodynamically decompensating patient or when there is imminent risk of asystole.
- Temporary transvenous pacing is used when patients that are pacemaker-dependent must undergo pacemaker revision (lead revision or replacement).

A. Strumwasser (✉) · B. Allen
University of Southern California, Los Angeles, CA, USA
e-mail: Aaron.strumwasser@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_20

20.4 Contraindications

- Stable bradyarrhythmias with minimal symptoms.
- Bradyarrhythmias with an escape rhythm (complete heart block or sick sinus syndrome with short infrequent pauses) where the patient is only mildly symptomatic.
- Tricuspid valve mechanical prostheses.
- Right atrial thrombus.

20.5 Patient Preparation and Positioning

- Preferred cannulation sites for transvenous pacing include the right internal jugular vein (best site) and the left subclavian vein having demonstrated the highest rates of proper placement with best captures from insertion at these sites.
- Femoral cannulation should generally be avoided except in the patient who is anticoagulated or undergoing thrombolysis where bleeding is a concern. Femoral insertion is less likely to result in good placement in the absence of fluoroscopy and carries a higher venous thromboembolism and infection risk.
- Choose the correct pacing lead—transvenous pacing (TVP) catheters are usually balloon-tipped and come with intrinsic curvature at sizes 2, 5, 6, and 7 French.

20.6 Equipment (Fig. 20.1)

Multiple commercially available transvenous pacemaker kits exist. The operator should ensure familiarity with the specific product prior to use. General equipment includes:

- Mask, cap, sterile gown, sterile gloves, sterile drapes.
- Portable ultrasound with vascular probe.
- Pacemaker generator with battery and cable.
- Temporary pacing catheter.
- Electrocardiographic (ECG) machine/cardiac monitor.
- Sheath with integral hemostasis valve/side port and transcutaneous pacer and tissue dilator (Pacing Cordis Kit).
- Introducer needle (18G) and 0.035 guidewire.
- 10 mL syringe.
- 3 mL syringe for pacemaker balloon.
- Chlorhexidine solution/swab.
- Ampule 1% lidocaine no epinephrine.
- Catheter contamination sleeve.
- Alligator clip for attachment to EKG lead.
- Scalpel #11.
- Stopcock with three-way high flow.
- Suture.
- Sterile dressings including Tegaderm and Biopatch.

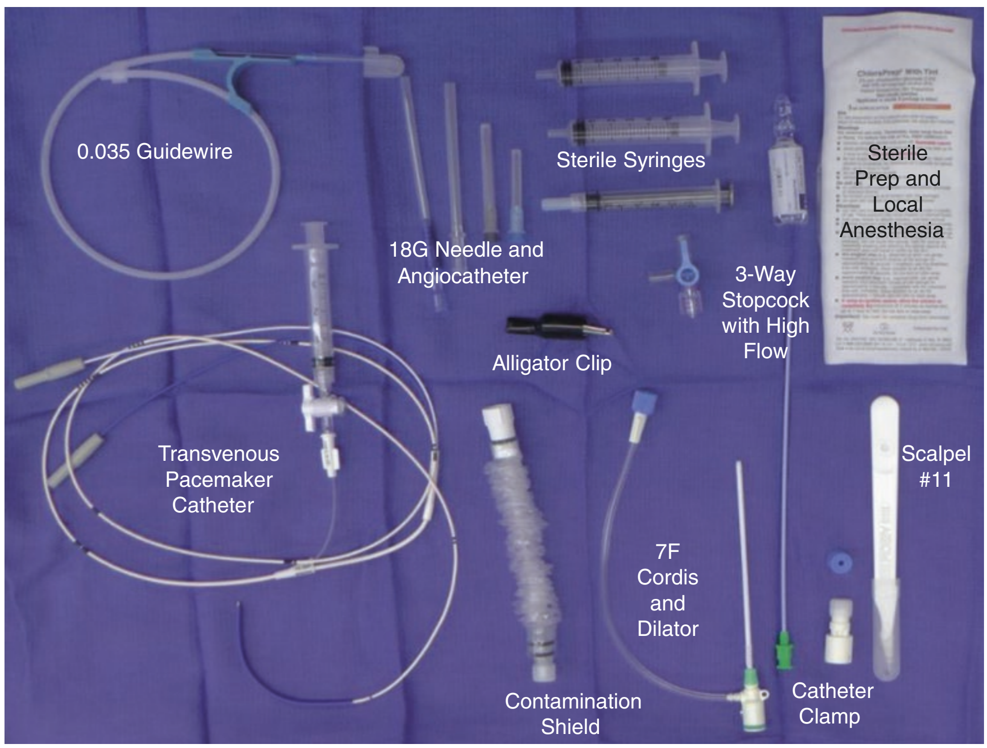


Fig. 20.1 Equipment necessary for temporary transvenous pacing

20.7 Surgical Technique

- Apply sterile prep and drape to the desired cannulation site.
- Remove protective sheath on pacing wire end, test balloon on pacing wire (1.5 mL) (Fig. 20.2), apply contamination shield (compressed) to pacer wire, and hand the end off of the sterile field.
- Perform ultrasound-guided venous cannulation of desired location (Figs. 20.3a–b and 20.4), place guidewire through needle (Fig. 20.5), advance Cordis catheter over wire using Seldinger technique (Fig. 20.6a–c), and remove the dilator.
- Prepare to insert the pacing wire by orienting it along its intrinsic curvature to optimize the probability of passing through the tricuspid valve and into the right ventricle (Fig. 20.7).

Fig. 20.2 Test the balloon on the transvenous pacemaker

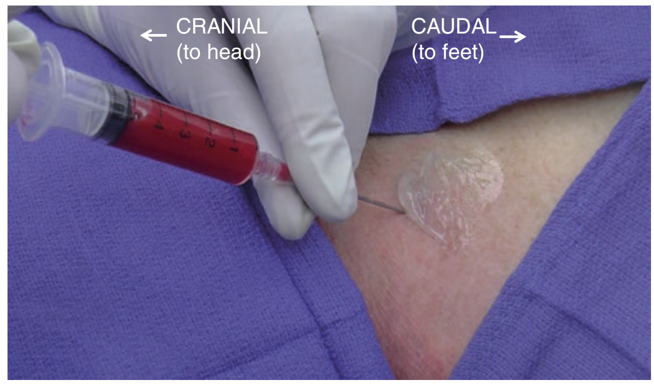
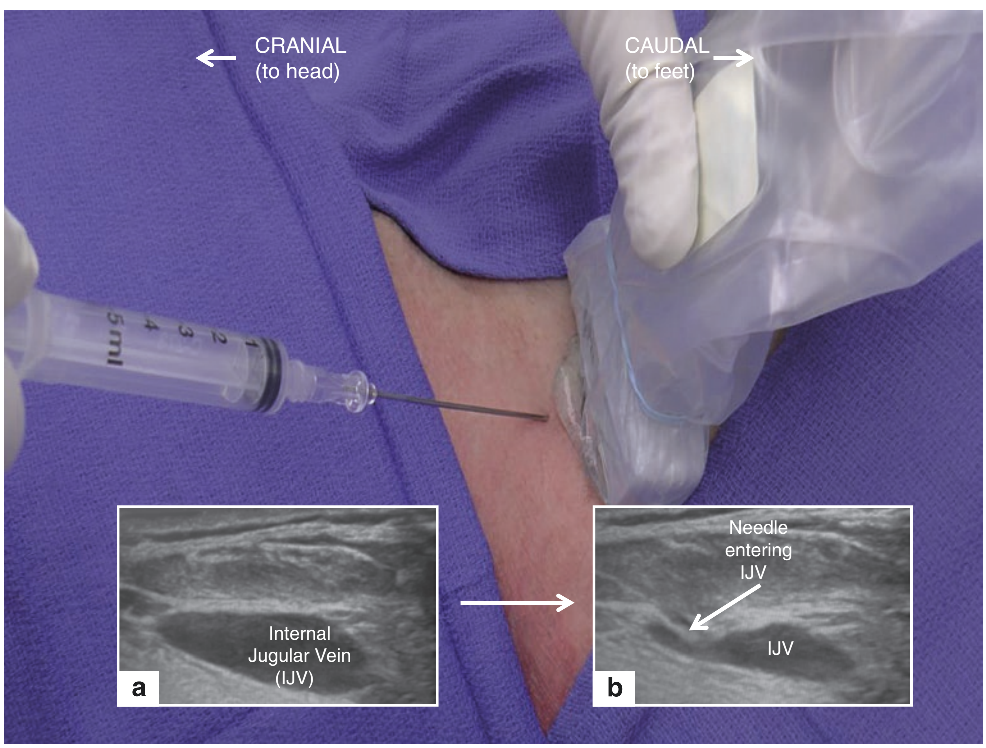


Fig. 20.4 Cannulation of the site is confirmed by aspiration of dark red venous blood

Fig. 20.3 Perform ultrasound-guided venous cannulation of the desired site (right internal jugular vein shown). Visualize the vessel in the transverse orientation (**a**) and cannulate under direct visualization (**b**)



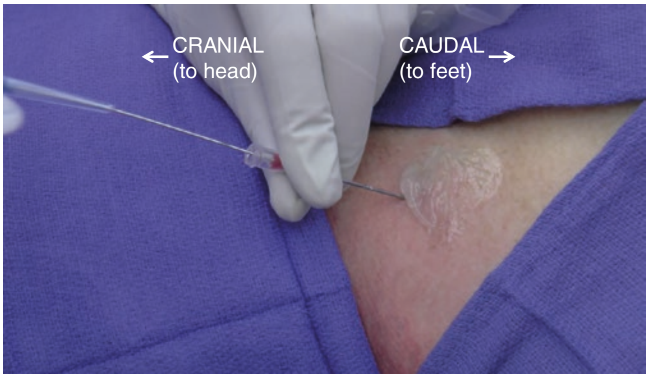


Fig. 20.5 Advance the guidewire carefully through the needle, confirm with ultrasound both in transverse and longitudinal orientation that the guidewire is in the vein

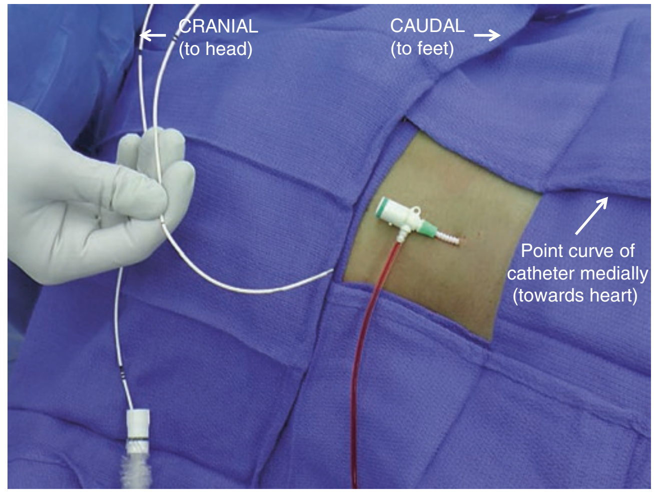


Fig. 20.7 Align the transvenous pacemaker catheter along its natural curvature, medially toward the heart. This will maximize the chance of passing through the tricuspid valve into the right ventricle

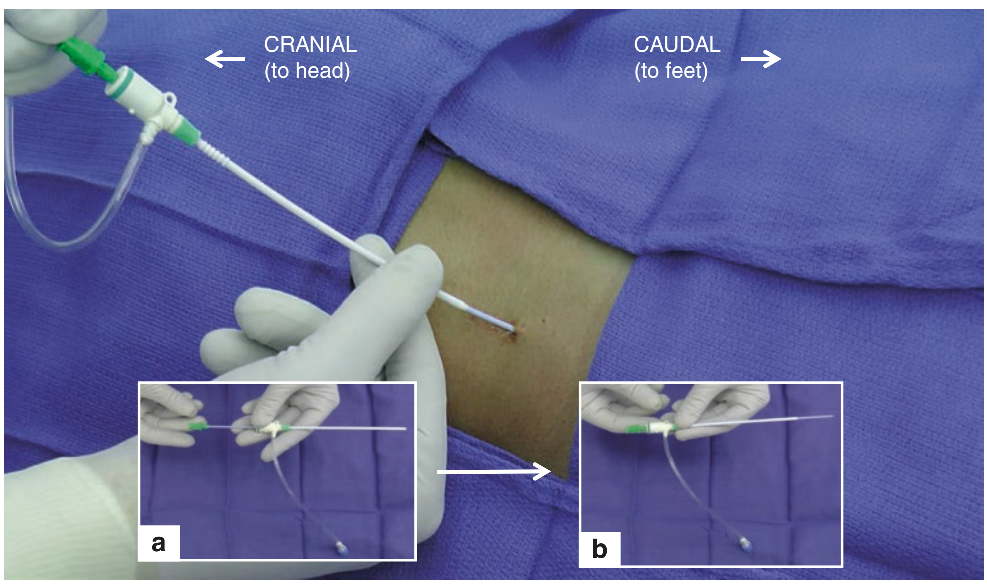


Fig. 20.6 Assemble the Cordis catheter and dilator as a single unit as shown (**a** and **b**). Make a small incision in the skin (through the dermis) at the percutaneous entry site. Insert the Cordis catheter and dilator over the guidewire in Seldinger fashion

20.8 A. Blind Insertion Technique

- Connect wires to pulse generator, (+) lead to (+) channel, (−) lead to (−) channel.
- Configure initial settings for pacer—output 20 mA (or maximum), sensitivity to asynchronous, rate 60–80 (or higher if higher heart rate desired goal).
- Next place the transvenous lead through the introducer sheath, and if patient has a pulse and the catheter has a balloon, it should be inflated once it has passed through the introducer, approximately at the 20 cm mark on the catheter (Figs. 20.8 and 20.9).
- Continue to advance the pacemaker wire with the balloon up. As it is advanced, the EKG will show pacer spikes. When the catheter enters the right ventricle and contacts the ventricular wall, a left bundle branch pattern (wide QRS complex) should be seen after every pacer spike (usually 40–50 cm) (Fig. 20.10).
- The balloon can now be deflated and the catheter secured in place.
- If during advancement you reach the 60–70 cm mark with no capture, deflate the balloon, pull the lead back to about 20 cm, and start over as you have almost certainly gone down the IVC instead of through the tricuspid valve.

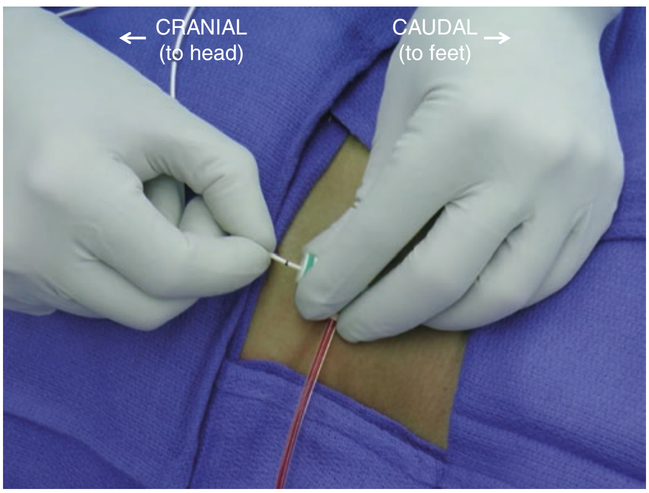


Fig. 20.8 Insert the transvenous pacer catheter through the sheath to 20 cm

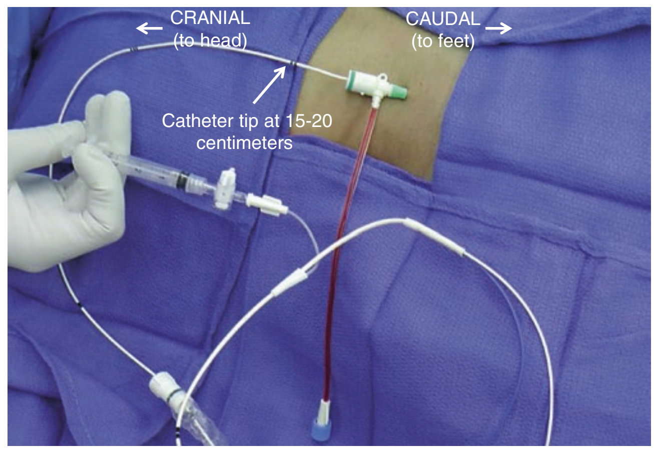


Fig. 20.9 Once the balloon tip has passed the distal end of the Cordis catheter (at approximately 20 cm), inflate the balloon

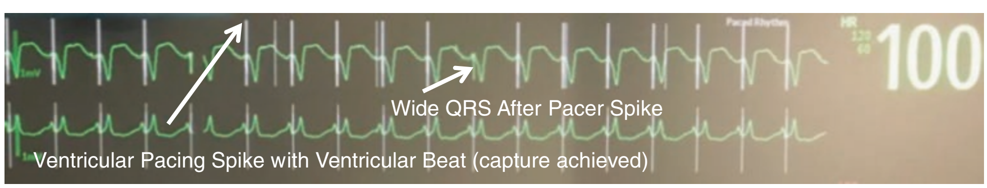


Fig. 20.10 As the balloon successfully enters the right ventricle, pacer spikes will appear on the ECG tracing

20.9 Final Manipulations Following Pacing Catheter Insertion

- When the lead hits the apex feel for a "slack" pressure—the lead is in the right place and the bend of the lead is passing through the tricuspid valve. The bend will allow for small motions of the heart and prevent dislodgement and loss of capture. Secure the lead in place.
- Stretch and affix the contamination shield to catheter hub at this location, and secure the catheter to the skin with suture and apply a sterile dressing (Figs. 20.11, 20.12 and 20.13).
- Connect the leads to the pulse generator (screw tightly and securely) (Fig. 20.14a–c).
- Obtain a post-procedure CXR to rule out pneumohemothorax and to assess for pacer wire location in or near the right ventricular apex (Fig. 20.15).
- Pacing (output) and sensing thresholds need to be tested after placement.
- The pacing threshold is the minimum current needed to obtain capture. To obtain the pacing threshold, set the pacer rate at least 10 beats/min higher than the patient's intrinsic rate, set the sensitivity to asynchronous, and set the pacing output to its highest level. Then slowly reduce the output until capture is lost which represents the pacing threshold. Set the output to double (two times) the threshold to ensure capture. The ideal pacing threshold is 1–3 mA, and the catheter should probably be repositioned if the threshold is above 6–8 mA.
- The sensing threshold need be tested only if the pacemaker will be used in a demand mode (if the patient has an underlying rhythm to be "sensed") which is unusual in the emergency setting.
- To test the sensing threshold, set the rate 10 beats/min slower than the patient's intrinsic rate and the sensitivity to its lowest level; the pacemaker should show sensing at this level. Slowly dial up the sensitivity (raise the level) until the pacer stops sensing, that is, the sensing threshold. Now lower the sensitivity level to below the sensing threshold to ensure adequate sensing (usually by half).

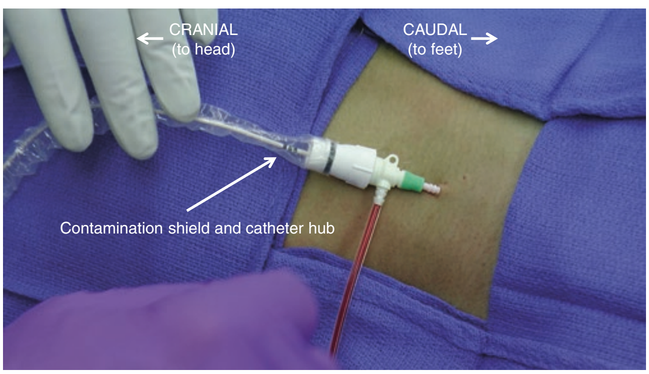


Fig. 20.11 Stretch and affix the contamination shield to catheter hub

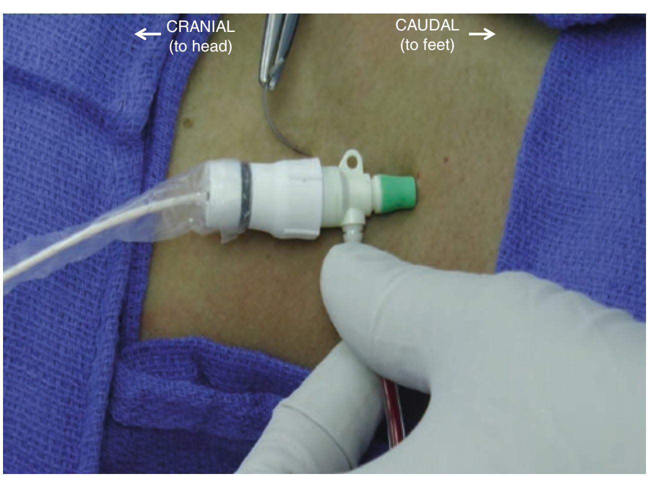


Fig. 20.12 Suture the catheter to the skin

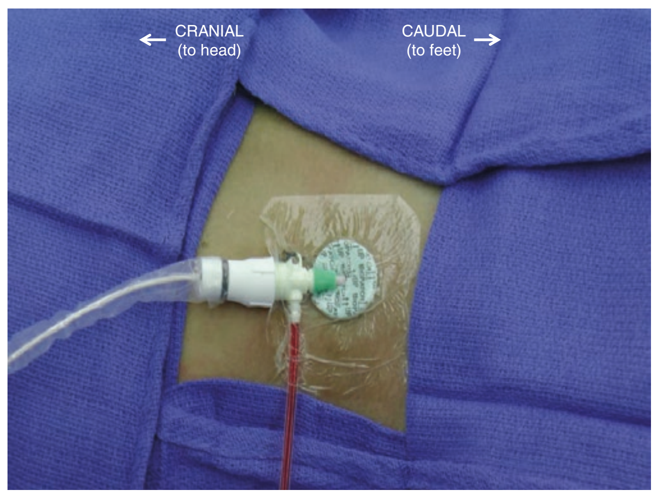


Fig. 20.13 With the catheter secured by suture, apply a sterile dressing

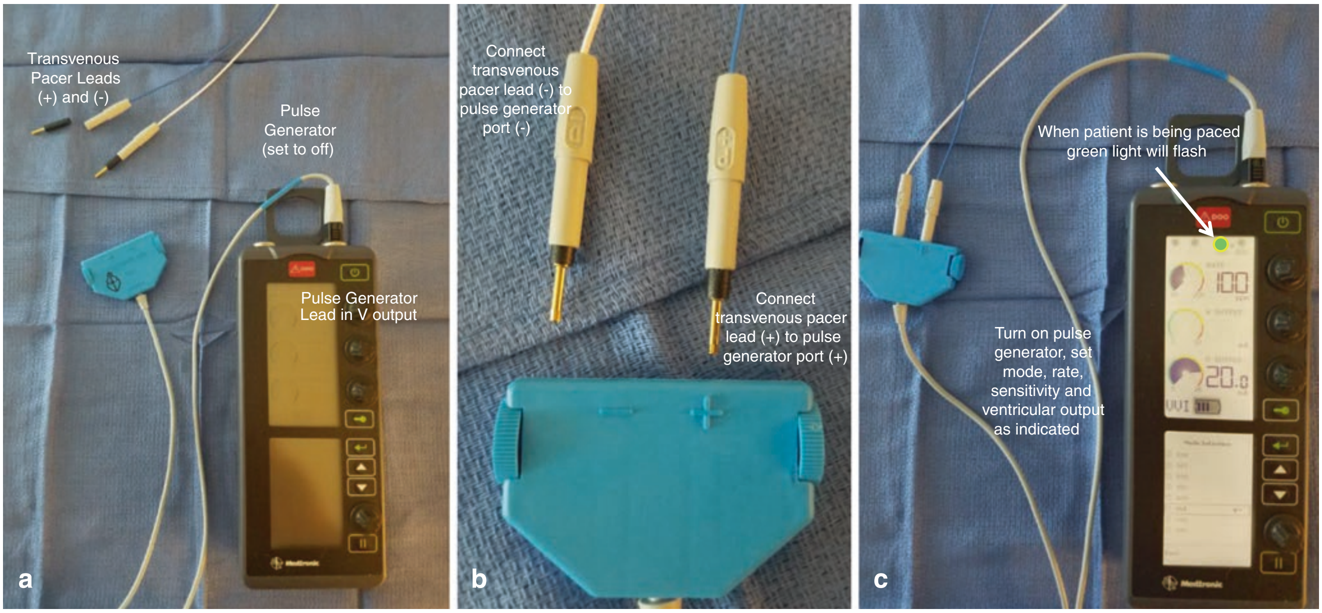


Fig. 20.14 (**a**) At the distal end of the transvenous pacer, assemble the pacer leads and connect the pulse generator leads to the ventricular port. (**b**) Verify that the pacing leads are corrected to the appropriate polarity. (**c**) With the leads inserted correctly, turn on the pacemaker and set as desired (mode, rate, output, and sensitivity). With appropriate capture, the light will flash signifying the patient is being paced

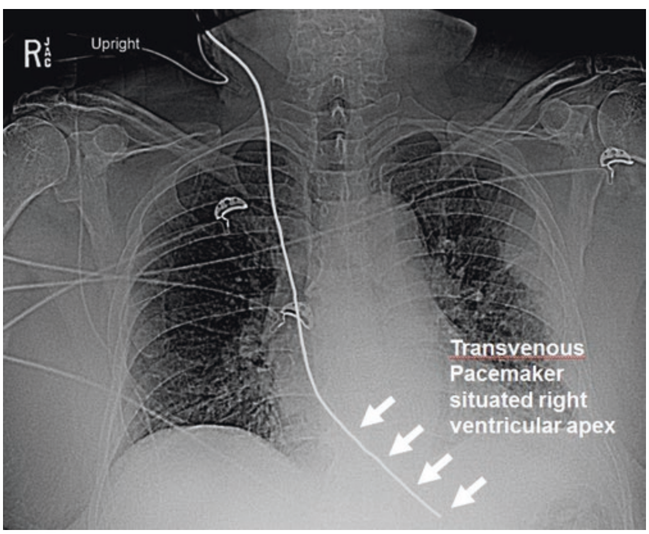


Fig. 20.15 Post-procedure X-ray demonstrating cannulation of the right internal jugular vein with appropriate placement of the transvenous pacemaker at the right ventricular apex. Appropriate placement is also confirmed by capture on the ECG monitor

20.10 B. Placement with Electrocardiogram (EKG) Guidance

- If placing with EKG guidance, attach the negative (distal) electrode from the pacing catheter to any precordial (V) EKG lead using an alligator clip. This allows the pacing catheter to serve as an intracardiac EKG lead so the physician can monitor the progression of the catheter as it approaches the right ventricle by analyzing the various EKG wave forms (Fig. 20.16a–f).
- Place the transvenous lead through the introducer sheath and if patient has a pulse and the catheter has a balloon, it should be inflated once it has passed through the introducer, approximately at the 20 cm mark on the catheter.
- Continue to advance the catheter with the balloon up. A superior vena cava location results in low amplitude and negative polarity P waves (since it is above the right atrium) and negative polarity QRS complexes.
- As the catheter tip enters the right atrium, the P wave becomes larger and is negative (as is the QRS), but it becomes biphasic and positive as it moves down (below) the atrium and reaches the tricuspid valve. If the catheter exits the right atrium into the IVC, the P wave will remain positive, but the QRS will become smaller as the catheter moves away from the heart (Fig. 20.17a, b). This positive P wave would be what was seen first with a femoral approach as the catheter approached the right atrium from below.

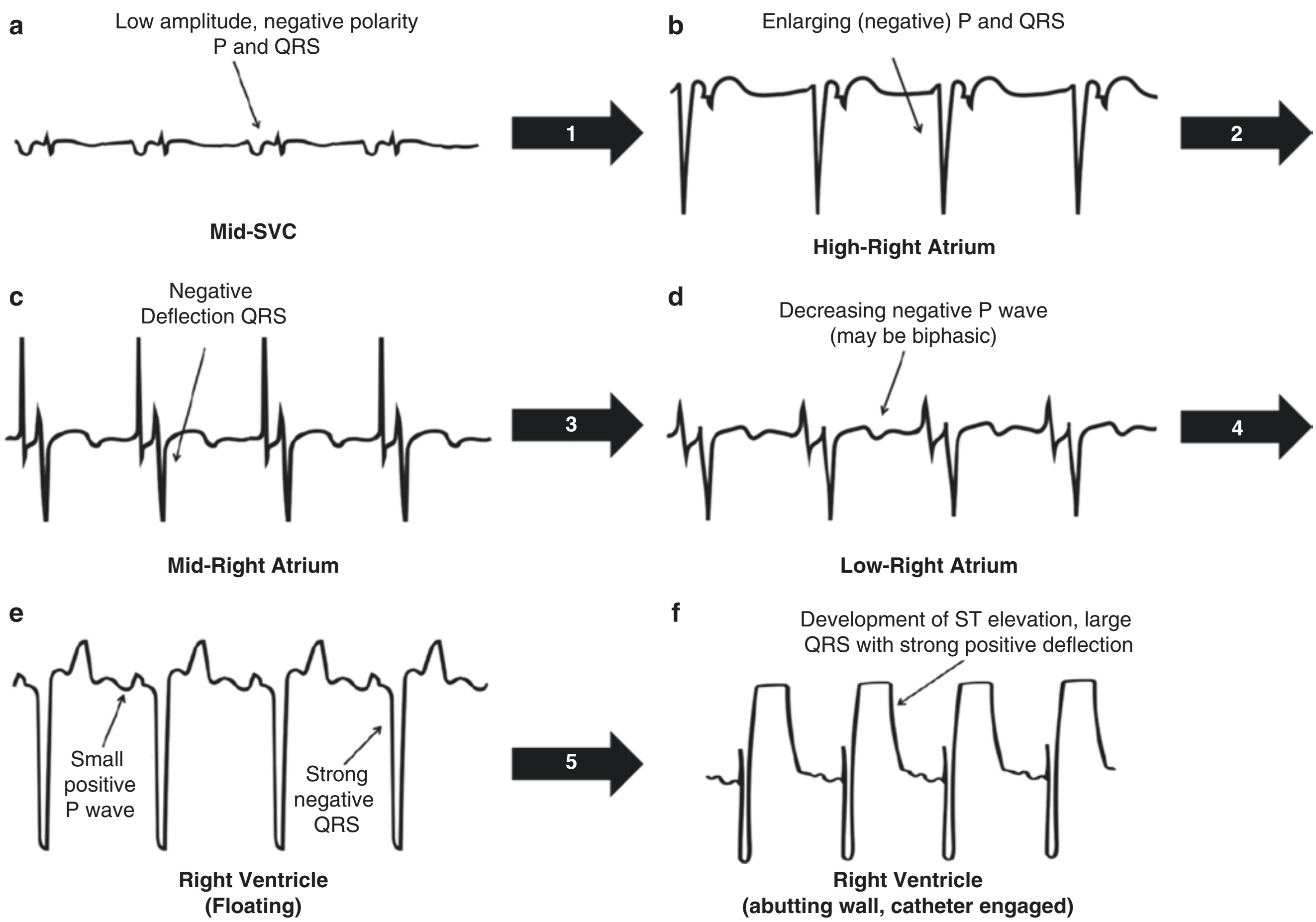


Fig. 20.16 Transvenous catheter progression from mid-SVC (**a**) → high right atrium (RA) (**b**) → mid RA (**c**) → low RA (**d**) → right ventricle (RV) (free) (**e**) → RV (against wall) (**f**). (**a**) Mid-SVC position of transvenous catheter. ECG tracing demonstrates low amplitude and negative deflection of P and QRS waves. (**b**) High right atrium position of transvenous catheter. ECG tracing consists of enlarging negative P and QRS wave deflections. (**c**) Mid-right atrial position of transvenous catheter. ECG tracing demonstrates negative deflection QRS wave. (**d**) Low right atrial position of transvenous catheter. ECG demonstrates decreasing negative P wave deflection. On occasion the P wave in the low atrial position can appear biphasic. (**e**) Floating transvenous catheter in the right ventricle. As opposed to an abutted right ventricular position (large ST elevation), the floating transvenous catheter is characterized by a small positive P wave and strong negative QRS wave. (**f**) Right ventricular position with transvenous catheter engaged on the ventricular wall. Characteristic findings on ECG are a large QRS with strong positive deflection

- Right ventricular entry by the lead is signaled by a small positive P wave and a deeply negative QRS. When the catheter tip engages the right ventricle, it will show a current of injury (ST segment elevation) with a large QRS.
- If the catheter transverses the right ventricle into the pulmonary artery, the P wave will again become negative as the catheter moves above the right atrium and the QRS smaller (Fig. 20.18a–e).
- To prevent this, it is often helpful to deflate the balloon once the catheter passes through the tricuspid valve to help guide the tip into the right ventricle apex instead of being carried into the pulmonary artery.
- Frequent premature ventricular beats or ventricular tachyarrhythmia also signifies the lead has advanced into the right ventricle myocardium. If available fluoroscopy will allow direct visualization of the lead to the proper location.
- As in the blind technique, the pacing catheter should now be connected to the pacemaker generator and capture demonstrated. If there is no capture, the catheter should be repositioned.
- Perform “Final Manipulations” as detailed at the end of the Blind Insertion Technique above.

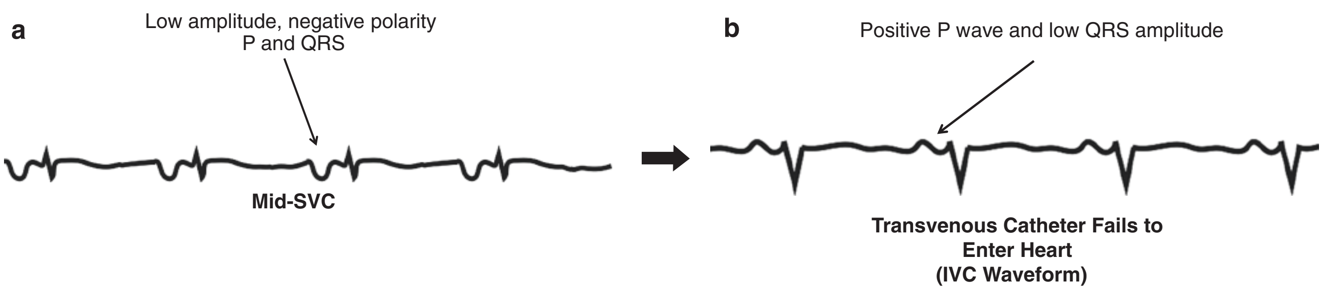


Fig. 20.17 Aberrant ECG waveforms in the IVC. As the catheter transitions from the mid-SVC to the IVC (bypasses the heart, conduction is inverted), the waveform is characterized by formation of positive P wave deflection and low QRS amplitude. (**a**) Mid-SVC position of transvenous catheter. ECG tracing demonstrates low amplitude and negative deflection of P and QRS waves. (**b**) IVC ECG waveform characterized by positive P wave and low QRS amplitude

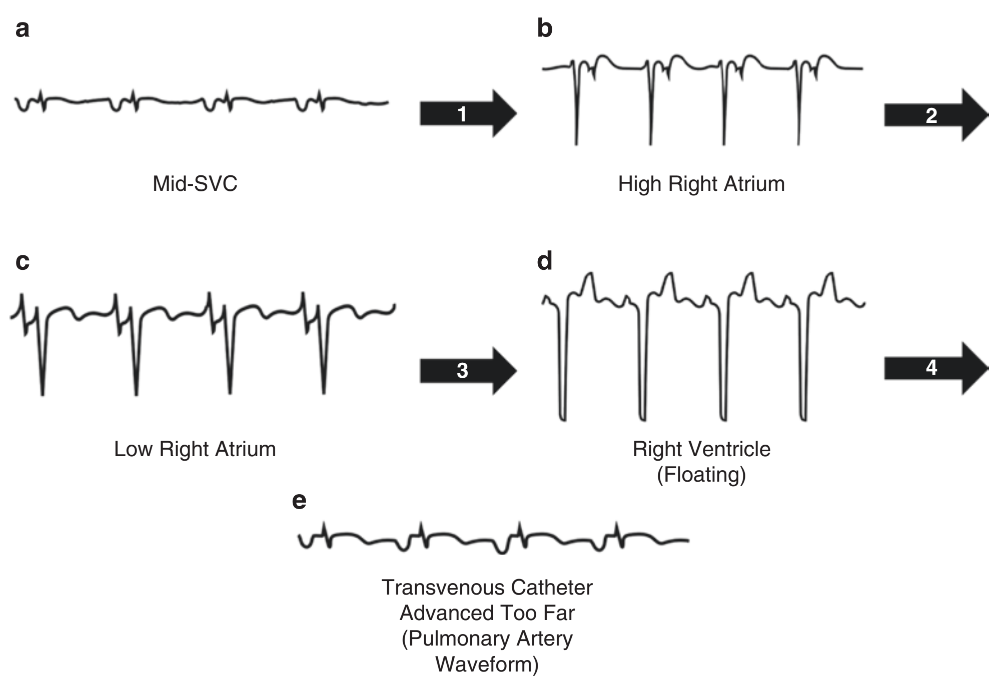


Fig. 20.18 As the catheter is advanced through the heart into the pulmonary artery, the P wave will become increasingly negative as the catheter moves above the atrium (away from normal electrical conduction) and the QRS smaller. (**a**) Mid-SVC position of the transvenous catheter. (**b**) High right atrial position of the transvenous catheter. (**c**) Low right atrial position of the transvenous catheter. (**d**) Floating transvenous catheter in the right ventricle. (**e**) Transvenous catheter advanced into the pulmonary artery

20.10.1 Tips and Pitfalls

- The blind insertion technique is often preferred by inexperienced operators or in an emergency since it is faster and technically less complex. However the operator receives virtually no feedback as the catheter is advanced making this a major drawback of this technique.
- If possible avoid the left subclavian vein if you anticipate the patient will need a permanent pacemaker as this is the preferred location for its insertion.
- The right internal jugular vein results in the highest successful placement in the right ventricle.
- Ultrasound can be very helpful in placing the pacing catheter if the operator has experience in bedside ultrasonography. The subxiphoid four-chamber view is preferred. The pacing wire appears as a bright linear hyper-echogenic structure as it enters the heart and can be followed as it transverses the tricuspid valve into the right ventricle and contacts the ventricular apex (Fig. 20.19).
- Failure to connect the lead to the pulse generator securely can lead to life-threatening asystole in the event the lead becomes disconnected.
- Never forget to have a new battery (or at least to check the battery) in the pulse generator prior to insertion.
- Avoid inappropriate initial settings—low mA output or low sensitivity.
- Failure to achieve capture or high mA (> 20 mA) needed to achieve capture (lead not in the right place or wire not functional) means the lead must be repositioned.
- Pacing the diaphragm indicates the pacing lead is near the IVC, and not in the heart.
- Overinflation of balloon can result in rupture that can instill air into the heart resulting in an air embolus.
- Failure to inflate the balloon increases the chance of vascular or cardiac damage and makes placement more difficult.
- Failure to adequately secure lead can allow pacing lead movement, and dislodgment (pacer won't fire anymore) can lead to life-threatening bradycardia and cardiovascular collapse.
- Failure to monitor for changes in sensitivity threshold or capture (pacing) threshold (needs to be checked every nursing shift) can lead to sudden pacemaker non-function.

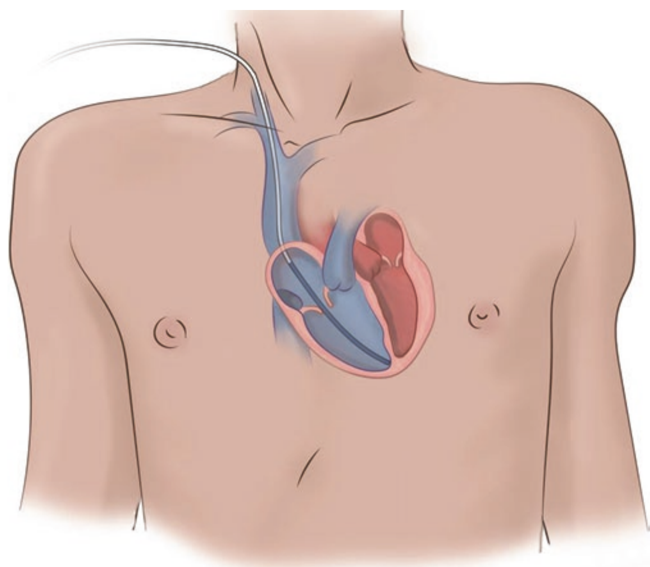


Fig. 20.19 Illustration demonstrating transvenous pacemaker advanced into the apex of the right ventricle

Part IV

Kidneys

21 Dialysis Access Catheters

James Bardes and Meghan Lewis

21.1 Surgical Anatomy

(Refer to "Central Venous Catheters," Chap. 12)

21.2 General Principles

- A vascular access catheter is indicated when a patient requires renal replacement therapy. Common indications for renal replacement therapy in the ICU include:
  - Refractory acidosis
  - Hyperkalemia
  - Volume overload
  - Symptomatic uremia
  - Overdose with a dialyzable toxin
- Consent from the patient or family member should be obtained whenever possible. Risks include:
  - Arterial puncture
  - Pneumothorax
  - Infection
  - Venous obstruction or thrombosis
  - Air embolus
- The right IJ is the preferred site for placement of a temporary dialysis catheter, due to the short straight course it takes to the superior vena cava. This provides the least hindrance to the flow of blood for hemodialysis.
- The femoral vessels are the next preferred site. Though the course of the vessels is generally straight, this site has a significantly higher incidence of infection and also potentially limits the patient's mobility.

J. Bardes · M. Lewis (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: meghan.lewis@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_21

- Catheters in the left IJ will require two angulations on course to the superior vena cava, which can lead to difficulty achieving adequate flow for dialysis, as well as increased contact with the vessel wall (associated with thrombosis and stenosis).
- The subclavian vessels are the least preferred site due to the potential for subclavian vein stenosis. If a temporary dialysis catheter must be placed in the subclavian vein, the dominant arm should be selected, reserving the non-dominant arm for creation of an arteriovenous fistula or graft.
- A chest X-ray should be obtained after insertion of a vascular access catheter in the IJ or SC. The catheters are semi rigid, so the tip should not be in the heart (Fig. 21.1).

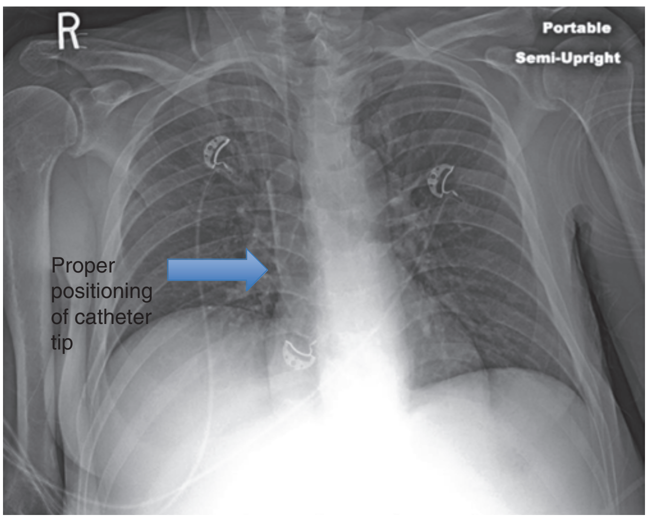


Fig. 21.1 Right internal jugular catheter with proper positioning of the catheter tip

21.3 Instruments

- Many different types of vascular access catheters exist.
  - These can have straight or curved access sites.
  - The outer diameter of the catheters can vary, between 11 and 14 French. Larger diameters generally allow for less hindered flow.
- Multiple commercially available kits exist for vascular access catheter (Fig. 21.2). The operator should ensure familiarity with the specific product prior to use.
- General contents of the kit include:
  - 18 gauge needle for accessing the vein
  - 10 cc syringe
  - Guide wire
  - Scalpel
  - Multiple dilators
  - Catheter
- Additional equipment which may not be included in the kits:
  - Chlorhexidine prep
  - Sterile drapes, gloves, and gown
  - Local anesthetic
  - Appropriately sized needles
  - Additional syringes
  - Sterile saline
- Ultrasound Equipment
  - High-frequency (greater than 7 MHz) probe for optimal resolution of superficial structures
  - Sterile probe cover

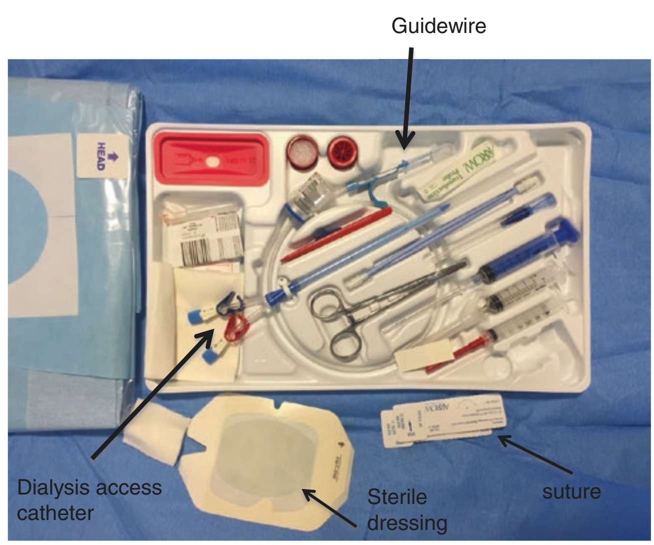


Fig. 21.2 Dialysis access catheter kit with the double lumen catheter, guide wire, syringes, needles, and sterile drapes and dressing

21.4 Positioning

(Refer to "Central Venous Catheters," Chap. 12)

21.5 Technique

- The procedure should be performed under full sterile conditions, including full-body draping, gown, mask, and sterile gloves.
- The vein should be punctured, wire inserted, and stab incision created in the skin as described in the "Central Venous Catheters" chapter (see "Central Venous Catheters," Chap. 12, Figs. 12.11–12.14).
- After the skin incision, the smaller dilator should be advanced with the operator's dominant hand over the wire and into the vessel (see "Central Venous Catheters," Chap. 12, Fig. 12.15). The end of the guide wire is then maintained with the non-dominant hand, while advancing the dilator with the dominant hand. The dilator should not be advanced more than a few millimeters into the vein (this distance can be estimated based on depth of venipuncture).
  - Between advances of the dilator, the wire should be advanced and retracted slightly within the dilator to confirm that no false passage has been created with the dilator.
  - The dilator is then removed, and slight pressure should be applied to the insertion site to prevent excessive blood loss. This is of particular importance due to the large size of the secondary dilator (Fig. 21.3).
- The larger dilator should then be advanced over the guide wire in similar fashion and then removed.
- The vascular access line should then be advanced over the guide wire and advanced to the appropriate length (Fig. 21.4):
  - R IJ advance 12–15 cm
  - Femoral veins advance 19–24 cm
  - L IJ advance 15–20 cm
- The guide wire is then removed from the catheter and the free end clamped to avoid air embolism (see "Central Venous Catheters," Chap. 12, Fig. 12.17).
- A trace of blood should be drawn from each port with subsequent flushing of sterile saline to confirm function and to clear the line.
- The catheter is then secured to the skin with simple non-absorbable sutures (Fig. 21.5).
- Lastly, a sterile dressing is applied.
- A portable chest X-ray should be ordered after placement of an IJ or SC vascular access catheter.

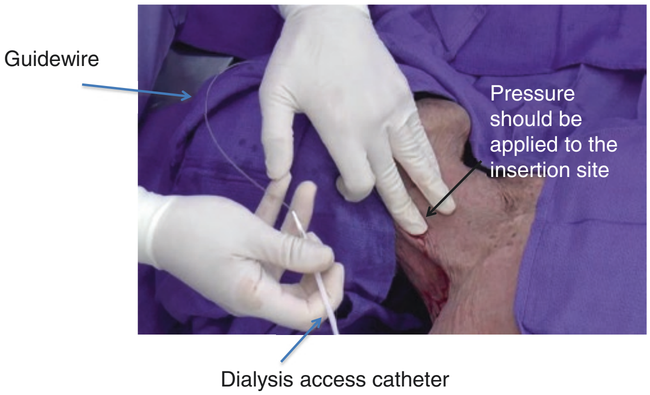


Fig. 21.3 Between passes of the dilator, firm pressure is applied to the insertion site (arrow) to prevent excessive blood loss

Fig. 21.4 The dialysis access catheter is advanced to the appropriate length

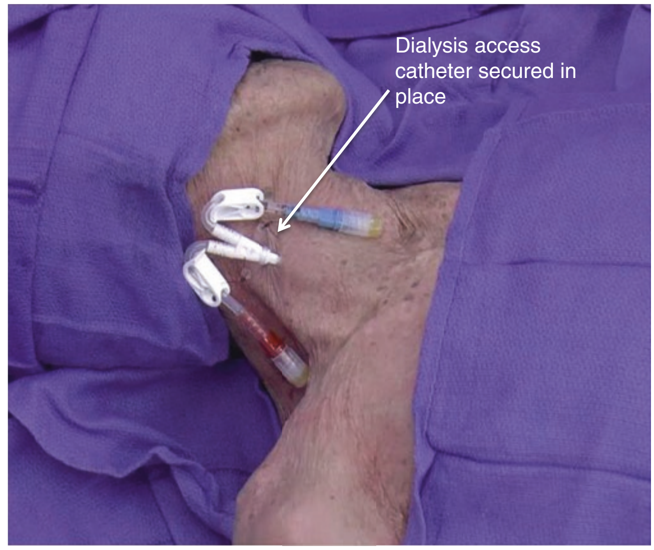


Fig. 21.5 The catheter is secured in place with nonabsorbable sutures

21.6 Maintenance

- Dialysis catheters should be used for dialysis access only. With the exception of emergencies, the catheters should not be used for blood draws, intravenous access, or infusions.
- When not in use, dialysis catheters should be filled with a lock solution to prevent thrombosis and maintain patency of the catheter. Either heparin 1000 U/mL or 4% sodium citrate can be used. Individual catheters will typically have the required instillation volume printed on the catheter.
- Prior to use, 6 cc of blood must be aspirated and discarded to prevent a bolus of anticoagulation.
- If the catheter is functioning poorly, a chest X-ray should be ordered first to confirm the catheter is correctly positioned. If the X-ray shows normal positioning, malfunction may be secondary to thrombus within the catheter. Tissue plasminogen activator (TPA) can be instilled within the catheter to improve flow and maintain patency. If necessary, 1–2 mg of TPA should be instilled for 60–90 min and then withdrawn from the catheter.

21.7 Removal

- Dialysis catheters should be removed when dialysis is no longer required. If patients develop a chronic need for dialysis, they should be evaluated for a tunneled dialysis catheter or arteriovenous fistula.
- If the patient is pharmacologically anticoagulated or coagulopathic, the catheter should ideally be removed after correction of coagulopathy or temporary cessation of pharmacologic anticoagulation.
- To remove internal jugular or subclavian catheters, the patient should be placed in Trendelenburg position, to decrease risk of air embolism.
- The sterile dressing is removed, the sutures are cut, and the catheter is slowly retracted while applying pressure over the vein.
- Pressure should be held on the site for at least 10 min or up to 30 min if there is a coagulation abnormality. Hemostasis should be confirmed.
- A sterile dressing is then reapplied.

21.8 Tips and Pitfalls

- Ultrasound guidance for placement of vascular access catheters is recommended.
- Inadequate advancement of the catheter can lead to poor flow during renal replacement therapy.
- Patients should be placed on a cardiac monitor during placement. If any ectopy occurs, the wire should be withdrawn until it ceases. Arrhythmias after catheter placement indicate catheter tip irritation of the right atrial wall (the catheter has been advanced too far).
- Advancement of the catheter too deep can cause atrial perforation and cardiac tamponade.
- The femoral vein should not be punctured above the inguinal ligament, as this is the external iliac vein. This is a non-compressible vessel, which increases the likelihood of a retroperitoneal hematoma after puncture or after line removal.
- If an arterial puncture occurs with the needle, simple pressure can be held at the site. However, if either of the dilators or catheter has been advanced into an artery, then placement of the line should be completed and it should be connected to a pressure bag. The catheter should not be used, and urgent surgical or interventional arterial repair will be required.

Part V

Nervous System

22 Intracranial Pressure Monitoring and Ventricular Drainage

Joshua Bakhsheshian, Katharina Pellegrin, and John P. Gruen

22.1 Anatomical Considerations

- Key craniometric landmarks include midline of the cranium (presumed location of sagittal sinus), nasion, ipsilateral tragus, ipsilateral mid-pupil, ipsilateral medial canthus, and the coronal suture.
- Kocher's point is an external landmark for the insertion point of a ventricular drainage catheter with the aim to avoid the superior sagittal sinus and precentral gyrus, for safe entry of the catheter in the frontal horn of the lateral ventricle.
- Kocher's point is approximately 1–2 cm anterior to the coronal suture, 2–3 cm lateral to midline (mid-pupillary line), and 11 cm posterior to the nasion (Fig. 22.1a–c). The coronal suture can be 11.5–13.5 cm from the nasion.

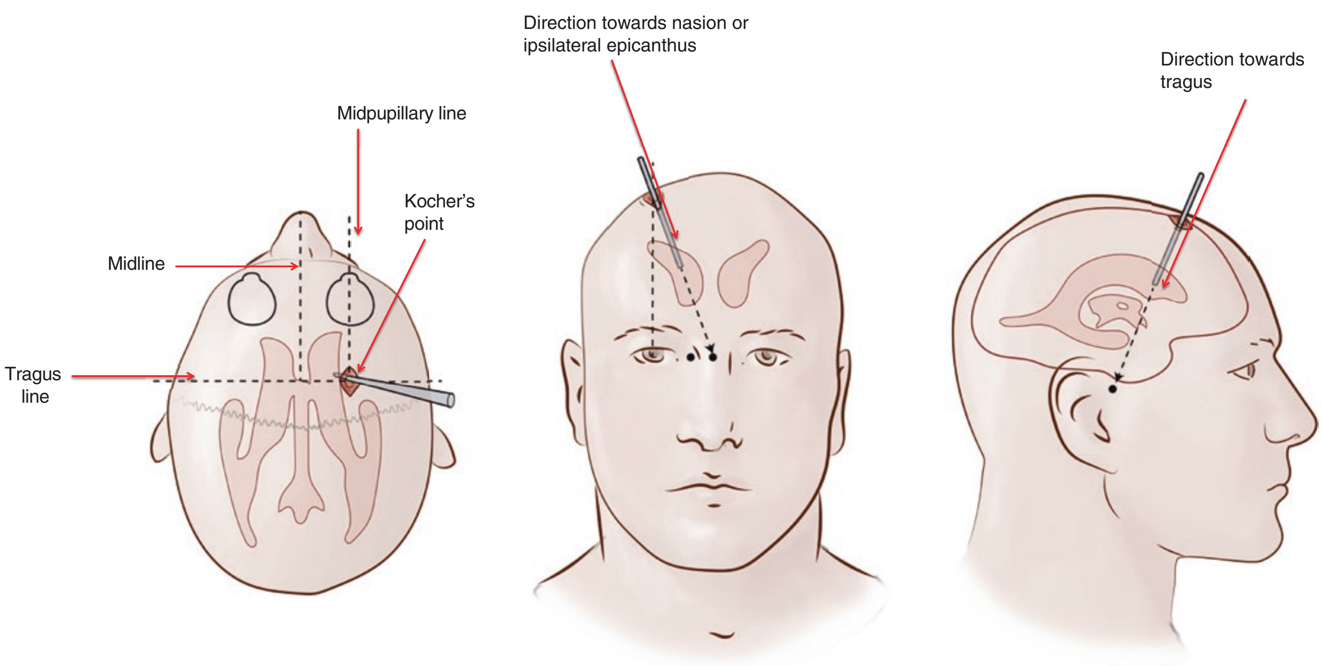


Fig. 22.1 Markings made for intraventricular catheter placement at Kocher's point

J. Bakhsheshian · K. Pellegrin · J. P. Gruen (✉)
Keck School of Medicine, University of Southern California, Los Angeles, CA, USA
e-mail: jpgruen@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_22

22.2 General Principles

- Depending on institutional policies, ICP systems can be placed in the emergency room, intensive care unit, or in the operating room.
- Elevated ICP can result in reduced cerebral perfusion and subsequent ischemic injury.
- Cerebral perfusion pressure (CPP) can be calculated from mean arterial pressure (MAP)—ICP.
- Generally, CPP should be >60 to avoid ischemia and <110 mm Hg to avoid hyperperfusion and/or cerebral edema.

22.3 Indications

- Based on a low-quality body of evidence available (Level IIB), the 2016 Brain Trauma Foundation Guidelines recommends the utilization of ICP monitors in the management of severe traumatic brain injury (TBI).
- Patients with severe TBI (GCS 3–8 after resuscitation, salvageable, with an abnormal computed tomography (CT) scan [or a normal CT scan with at least two of the following criteria: (a) >40 years of age, (b) posturing (unilateral or bilateral), or (c) systolic blood pressure < 90 mm Hg] may benefit ICP measurement and monitoring.
- A ventricular drainage system is generally indicated for the development of acute hydrocephalus.
- Acute hydrocephalus can result from subarachnoid hemorrhage, intraventricular hemorrhage, intraparenchymal hemorrhage, infection, brain tumors, or ventricular shunt failure.

22.4 Relative Contraindications

- Contraindications are generally relative and are more applicable to ventricular catheter placements.
- Coagulopathy including INR > 1.5, platelets <100,000.
- Receiving therapeutic anticoagulation.
- Trajectory traversing epidural hematoma, empyema, or active osteomyelitis.

22.5 Types of ICP Monitoring

- Intracranial pressure can be monitored in the intraparenchymal, ventricular, subdural, or epidural region.
- Intraventricular catheters (or external ventricular drains (EVD)) allow for both ICP monitoring and therapeutic drainage of CSF.
- They are the most accurate monitors available and allow for in situ recalibration as needed. As such, these remain the gold standard.
- Transducer-tipped catheters are easier and safer to place than intraventricular catheters, but their accuracy can decrease after several days.
- Transducer-tipped catheters are preferable when EVD catheterization is technically challenging (e.g., slit ventricles or shift due to mass effect) or active coagulopathies.
- Transducer-tipped catheters are usually placed intraparenchymal. Monitors in the subarachnoid, subdural, or epidural space are less reliable and are rarely used.
- Newer ICP monitor systems have been developed that provide both the function of a ventricular and transducer-tipped catheter in the same system.

22.6 Preparation

- Except in emergencies requiring immediate ventricular drainage, coagulopathies should be reversed.
- PT/INR, PTT, and platelets should be checked. Transfuse platelets and plasma as appropriate prior to procedure to achieve an INR of 1.5 or less and a platelet count of at least 100,000.
- A thorough medication history should be obtained, including use of antiplatelet agents (aspirin, clopidogrel, and others) and anticoagulant agents (warfarin, rivaroxaban, and others); appropriate reversal regimens should be administered prior to EVD placement.
- Periprocedural antibiotic prophylaxis and/or antibiotic impregnated ventricular catheters should be used to reduce the risk of infection.
- The patient should be adequately sedated to avoid involuntary movement during the procedure. A bolus of midazolam 2–4 mg with fentanyl 25 mcg–50 mcg can be given.
- The hair should be clipped around the incision and catheter exit sites. The site should be washed with antiseptic solution and draped in the standard sterile fashion. The operator should follow full sterile precautions, including sterile gown and gloves, surgical mask, eye protection, and hair covering.
- Generous local anesthetic (1–2% lidocaine with or without epinephrine) should be administered at the planned insertion down to the periosteum and planned area that the catheter will be tunneled through.
- Restraints should be used in a patient that is awake.
- Position the patient in neutral position with the top of the head slightly off the head of the bed. Place the head of bed at approximately 15–30°.
- Confirm secure airway. Continue oxygen at 5-10 L/min in non-inutbated patients by mask or nasal cannula. Position patient to allow monitoring of vital signs and pulse oximetry.

22.7 Techniques

- When the pathology is symmetric (e.g., bifrontal contusions), ICP monitors are generally placed in the non-dominant hemisphere (right hemisphere in right-hand dominant population).
- The dominant side may be preferred in cases with asymmetric pathology. For instance, when a craniotomy or hemicraniectomy is planned for the non-dominant side, significant skull defect is found on the non-dominant side or if the ventricle on the dominant side is trapped.
- Key anatomic landmarks (Figs. 22.1a–c and 22.2a–c) include the midline, nasion, ipsilateral tragus, ipsilateral pupil, medial canthus, and the coronal suture. The coronal suture can be 11.5–13.5 cm from the nasion.
- Intraventricular catheters are typically placed perpendicular to Kocher's point.
- Kocher's point is approximately 1–2 cm anterior to the coronal suture, 2–3 cm lateral to midline (mid-pupillary line), and 11 cm posterior to the nasion (Figs. 22.1a and 22.2a).

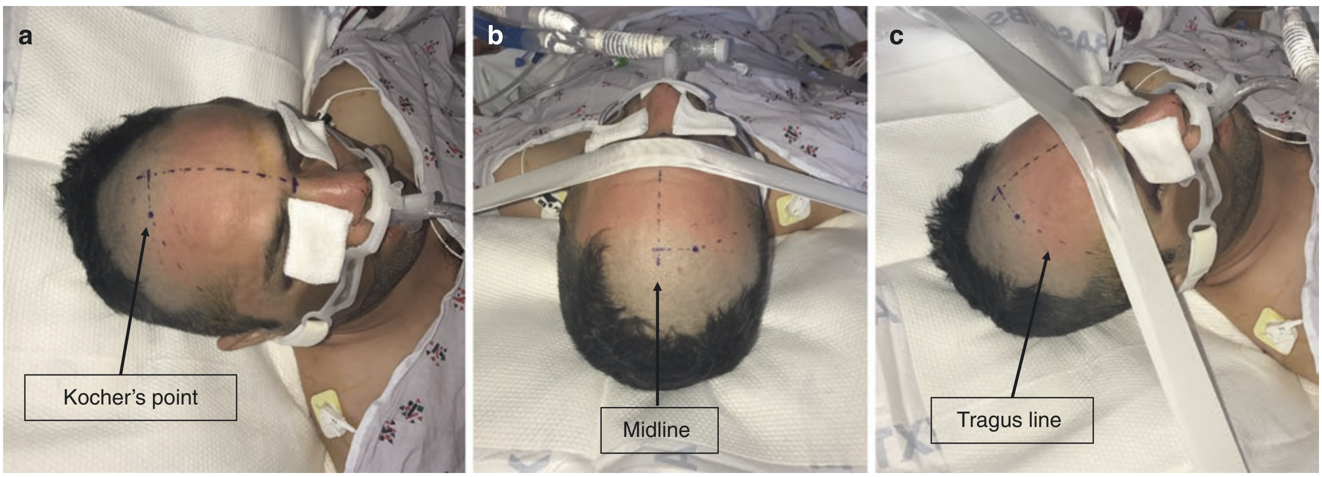


Fig. 22.2 Skin marking of landmarks for intraventricular catheter placement: (**a**) Kocher's point - site for cranial twist drill hole and passage of catheter, (**b**) midline - Kocher's point is a few centimeters lateral to the midline to avoid injury to sagittal sinus, (**c**) tragus line - catheter trajectory is aimed simulaneously at 1. ipsilateral inner canthus, and 2. tragus

22.8 Intraventricular Catheter

- Set up a nearby sterile tray with all of the supplies that are needed (Fig. 22.3).
- The hair is shaved and appropriate marks should be placed prior to taping/securing the head (which can distort the anatomy).
- A sagittal line can be marked along midline (marking 11 cm posterior to the nasion; Figs. 22.1a and 22.2b), and a coronal line can be drawn depicting the tragus line (in line with a perpendicular trajectory to the skull in the sagittal plane; Figs. 22.1c and 22.2c).
- A coronal line can also be made along the coronal suture to confirm that entry point is 1–2 cm anterior to this line (to avoid the motor strip).
- The head can be secured with silk tape (Fig. 22.2b–c).
- Prep and drape in the usual sterile fashion without covering key landmarks (Fig. 22.4a).
- Place a 1 cm horizontal incision with a surgical scalpel at Kocher's point down to the periosteum.
- The periosteum can be bluntly cleared from the skull with a Kelly forceps.
- The cranial twist drill is carefully held perpendicular to the skull drilling through the outer cortex (Fig. 22.4b).
- Once the outer cortex is breached, drilling becomes easier as the cancellous bone is encountered.
- The inner cortex of the skull is reached as the drilling becomes more difficult.
- Avoid downward pressure while drilling through the inner cortex.
- Remove bone debris with forceps once the burr hole is completed.
- Use an 18 gauge spinal needle to confirm that no residual bone is left in the burr hole.

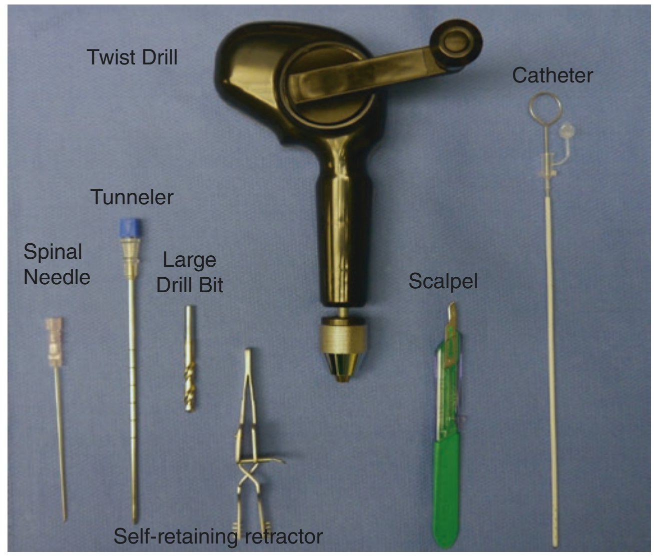


Fig. 22.3 Shown here are key items for ventriculostomy setup, including drill kit with large drill bit, #11 blade, scissors, ventricular catheter with catheter stylet in place

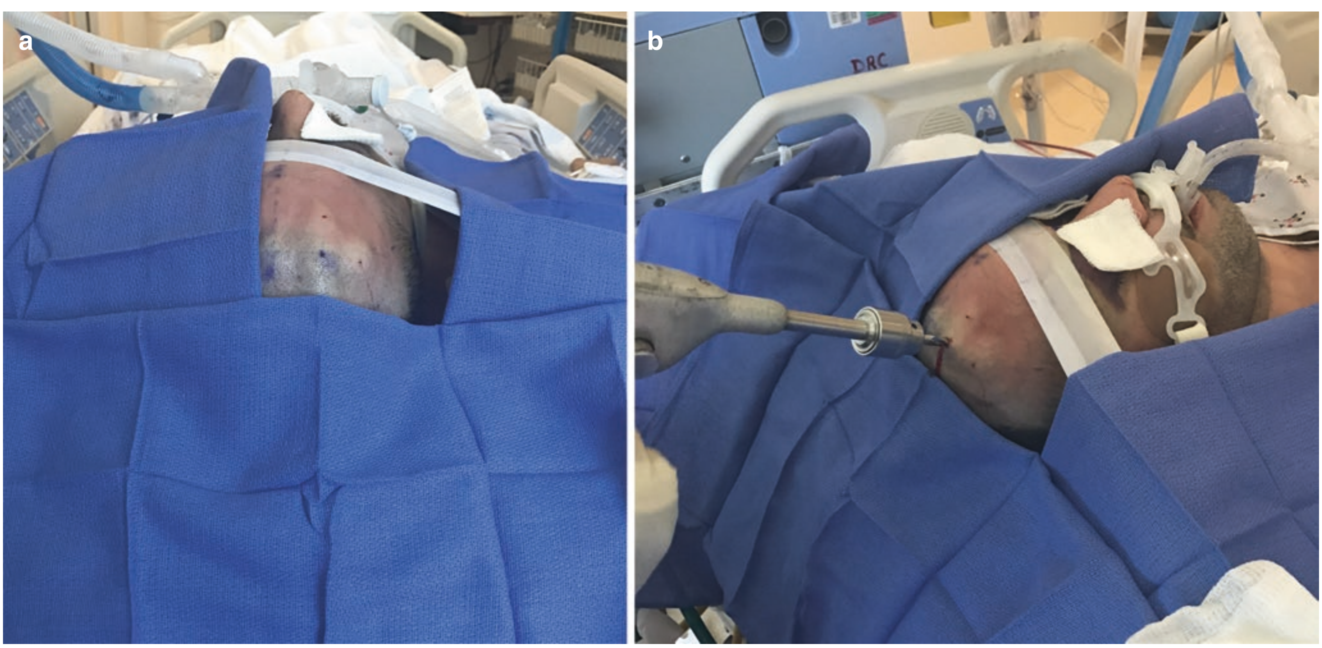


Fig. 22.4 Initial steps of draping and drilling. (**a**) Images demonstrating dressing while visualizing anatomic landmarks and (**b**) drilling perpendicular to the skull (**b**)

- The spinal needle or the tip of the surgical blade can be used to make a small durotomy for catheter entry (Fig. 22.5a).
- The ventricular catheter should be flushed with normal saline and held at 7 cm mark with the stylet in place.
- The ventricular catheter is then aimed perpendicular to the skull (in the sagittal plane) while aiming for the ipsilateral medial epicanthus and tragus line.
- Insert the catheter for 5 cm or until a pop is felt indicating entry into the frontal horn of the lateral ventricle.
- The stylet can be kept or removed and passed an additional 1 cm for entry into the foramen of Monro (Fig. 22.5b, c).
- Avoid advancing the catheter beyond 7 cm, and avoid excessive drainage of CSF during ventricular cannulation.
- If CSF is not encountered, two additional attempts may be made directing the catheter more medial, either toward the nasion or to the contralateral medial canthus.
  - Flush out all material in catheter before reattempting another pass.
  - Occasionally, the lack of CSF return may be due to low intraventricular CSF pressure. Therefore, a 10 cc syringe of sterile saline can be used to carefully inject 3–5 cc in the catheter; the head of bed can be dropped, then removing the syringe to observe for return of pulsatile flow which can confirm placement in ventricular system.
  - If CSF is not encountered after three attempts, the procedure should be performed by a more experienced physician under stereotactic guidance or aborted with placement of an intraparenchymal ICP monitor instead.
  - If multiple passes were made for ventricular catheterization, a CT head should be obtained to evaluate for new intracranial hemorrhage.
- At this point, a trocar is inserted through the incision and adjacent to the catheter entry point and tunneled posteriorly ~5 cm along the periosteum before penetrating through the scalp (Fig. 22.6a).
- The distal part of the catheter is then attached to the distal blunt end of the trocar to pull the catheter through (Fig. 22.6b).
- Secure the catheter and scalp incisions with nylon sutures at least at three points.
- Have an assistant prime the drainage system's tubing with sterile saline.
- Attach the tubing system for the external drainage system and apply sterile dressing.
- Have an assistant hang the collection system so that the transducer is at the level of the external auditory meatus (tragus) reflecting the foramen of Monro.
- Once the transducer is at the level of the EAM, the EVD tubing is closed to the patient and the pressure monitor reading system is zoeroed.

Fig. 22.5 Durotomy and catheter placement. (**a**) 18G spinal needle durotomy (**b**) catheter placement while visualizing landmarks (c) stylet removal with CSF

- Open the EVD tubing system to both the transducer and the patient. The EVD system should now be calibrated to provide ICP readings. Confirm the existence of a proper triphasic ICP waveform on the monitoring system.
- Open the EVD tubing system to drain CSF at the desired setting. Confirm that CSF is flowing through the collection system when the pressure threshold is lowered.
- CT scan can be used to evaluate progression of neurologic injury and placement of ventricular catheter.

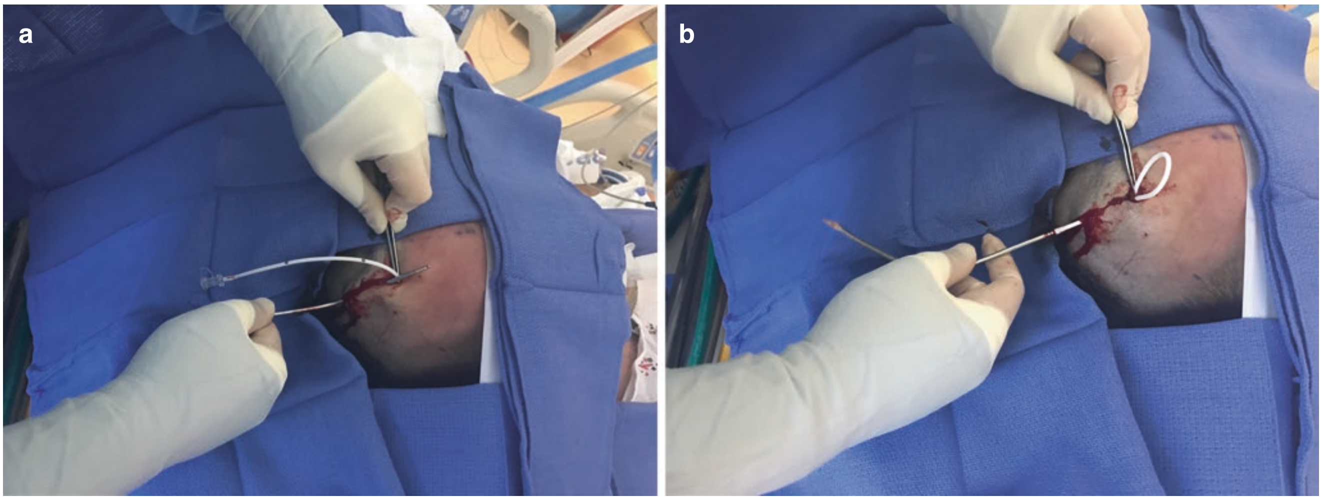


Fig. 22.6 Tunneling with trocar. Images demonstrating trocar placement and exit site (**a**) and (**b**) distal catheter attached to tunneling trocar

22.9 Transducer-Tipped Catheters

- The initial setup, sterilization, draping, and anesthesia are similar as previously mentioned.
- The ICP-monitoring bolt can be placed at Kocher's point, but since this does not require ventricular entry, entering slightly more anterior and more lateral avoids the risk of running into large draining veins.
- The incision can be made similar to described above.
- Attach the drill bit included with the ICP monitor kit (usually smaller than standard drill bits). A small Allen wrench is included with the drill bit to adjust the bit guard.
- Once dural access has been obtained, insertion of the ICP monitor should follow manufacturer guidelines. At our institution, the Camino™ ICP bolt is used (Fig. 22.7).

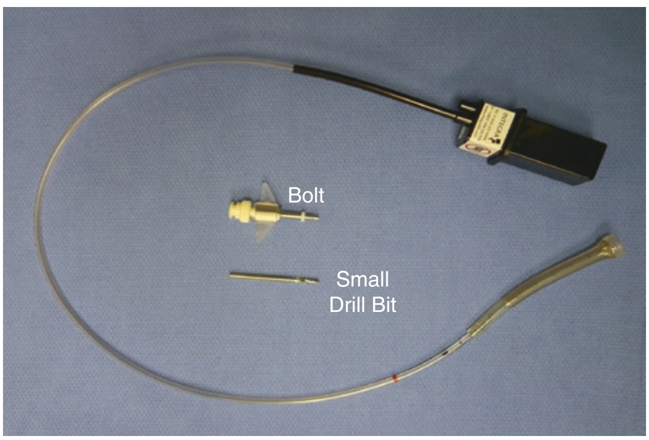


Fig. 22.7 Key items for ICP monitor placement with transducer-tipped catheter

- Generally, the bolt is screwed in finger tight.
- The fiber-optic probe must be connected and zeroed prior to insertion.
- Then the compression cap on the bolt is rotated to loosen and remove the stylet.
- At this point, the fiber-optic probe can be placed through the bolt at the referenced depth (for parenchymal placement), and the compression cap is tightened to secure the stylet, making sure it does not move.
- Redundant tubing can be taped around the bolt for securement.
- Sterile dressing is then applied.
- It should be noted that a bolt placement distorts the anatomy of CT head scans by causing artifacts.

22.10 External Ventricular Drainage Waveforms and Troubleshooting

- Waveforms obtained from ICP monitors are related to cardiac and respiratory cycles.
- Each wave has three peaks (triphasic) with Peak 1 representing arterial systolic pulsation, Peak 2 representing intracranial compliance, and Peak 3 representing aortic valve closure (Fig. 22.8).
- Normal ICP waveforms demonstrate Peak 1 with the highest amplitude, Peak 2 next highest, and Peak 3 as the lowest.
- If Peak 2 is higher than Peak 1, this may indicate elevated intracranial pressures.
- If the waveform is flat, check for causes of obstruction, like clogs or kinks. A collapsed ventricle should also be considered.

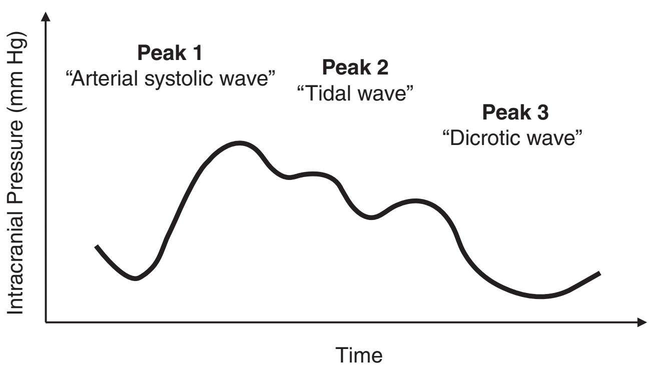


Fig. 22.8 Triphasic waveforms observed when measuring ICPs on monitor. Peak 1 representing arterial systolic pulsation, Peak 2 representing intracranial compliance, and Peak 3 representing aortic valve closure

- EVD tubing can be accessed between the collection system and the patient’s head to flush normal saline both distally and proximally, to clear coagulated blood and/or other debris from the catheter.
  – This is often a temporizing measure before definitive treatment can be performed (i.e., replacement of the catheter). Limit the volume of saline injections to avoid elevations in ICP.
- Recalibrate the EVD system as stated above.
- If the patient underwent a craniectomy, the waveform will likely be diminished. Therefore, lower the threshold for drainage to make sure the catheter is still working.

22.11 Removal of the ICP Monitor

- The duration of catheter placement has been associated with a higher risk for infection; therefore, the indication for their placement should be reassessed daily to remove when clinically appropriate.
- Prior to discontinuing an EVD, the same criteria for insertion should be followed. Labs should be reviewed and coagulopathies corrected. DVT prophylaxis should be held to reduce the risk of tract hemorrhage.
- CSF sampling for laboratory analysis can be sent during removal of EVD.
- The area of insertion should be prepped with proper sterile technique.
- Sutures securing the catheter in place should be removed. A 3–0 nylon suture with a needle drive should be placed on a nearby sterile tray.
- The catheter can be carefully withdrawn from the tunneled exit site. Once the tip of the catheter has exited, the opening of the site should be sutured closed.
- After discontinuation, a patient's neurologic exam should be followed to assess for deterioration due to hydrocephalus (which may require a ventriculoperitoneal shunt placement) or new hemorrhage.

22.12 Complications

- In rare cases, lacerating a vessel during dural opening with a spinal needle, trocar, scalpel, or other device can cause a new hematoma requiring an emergent evacuation. With any change in pupil exam on the ipsilateral side post-procedurally, an emergent head CT should be obtained.
- ICP monitors carry risks for infection. To decrease infection risks, the neurocritical care society recommends (1) one dose of antimicrobials prior to EVD insertion (2) against the use of antimicrobials for the duration of EVD placement (3) using antimicrobial-impregnated catheters as part of a comprehensive management protocol (4) limits the duration of ICP monitoring by removal when clinically appropriate.
- Deep placements of catheters (>8–9 cm) carry great risk to neurovascular structures, which can be life-threatening.

22.13 Tips and Troubleshooting

- In certain cases, an orthogonal trajectory at Kocher's point may be unsatisfactory (e.g., scaphoid skull anatomy). For this reason, preprocedural imaging should be reviewed to assess the ideal trajectory.
- Display the latest head CT so it is visible during procedure.
- Positioning of the patient is key to the success. Using the same angle of elevation with the head of the bed may increase the probability for successful cannulation of the ventricular system.
- A stop guard can be used on the drill bit to prevent entry into the brain parenchyma after breaching through the inner table.
- Scalp and bone bleeding can be considerable. Typically, hemostasis can be achieved with skin closure.
- Avoid wide incisions or removing too much of the periosteal layer to avoid skiving with the drill.
- Confirm that there are no bony edges in the burr hole, which can alter the trajectory of the catheter.
- Measure the distance to the frontal horn and foramen of Monro for pediatric patients, which generally require shorter catheters.
- After successful CSF cannulation, make sure that CSF flow persists after each step.

23 Lumbar Puncture

Caroline Park and Elizabeth R. Benjamin

The lumbar puncture may be used for diagnosis of infections and malignancies, administration of medications, and therapeutic drainage of cerebrospinal fluid.

23.1 Relevant Surgical Anatomy and Physiology

- The spinal cord ends at the L1–L2 level. Below this level, it becomes the cauda equina.
- The L4 vertebral body corresponds to the superior iliac crests. A line joining these two points corresponds to the L4 vertebral body. This line may correspond to a higher spinal level in women and in obese patients.
- Layers from posterior (superficial) to anterior (deep) (Fig. 23.1):
  - Skin
  - Subcutaneous fat
  - Supraspinal ligament
  - Interspinal ligament
  - Ligamentum flavum
  - Dura mater
  - Arachnoid mater
  - Subarachnoid space
- The normal opening CSF pressure should be between 10 and 20 cm H_2O, with expression of clear fluid.
- CSF should be sent for chemistry and hematology analysis (glucose, protein, WBC count) and cultures.

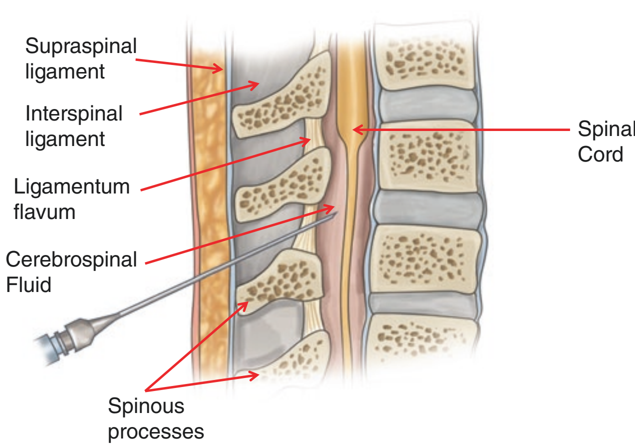


Fig. 23.1 Illustration of the layers of the spinal cord (superficial to deep). The first layer encountered is the skin and subcutaneous fat and then the supraspinal ligament, interspinal ligament, ligamentum flavum, dura mater, arachnoid mater, subarachnoid space, and then the spinal cord

C. Park · E. R. Benjamin (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: Elizabeth.Benjamin@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_23

23.2 Indications

There are three main indications to obtain a lumbar puncture: sampling of fluid, obtaining pressure measurements, or drainage and administration of agents. The most common indication for lumbar puncture is to confirm or rule out meningitis.

Obtaining a sample of the cerebrospinal fluid (CSF) for cellular, cytologic, chemical, and bacteriologic analysis:

- Bacterial, viral meningitis, or toxoplasmosis.
- Malignancy (i.e., metastatic cancer, lymphoma).
- Multiple sclerosis.

Obtaining pressure measurements, titrate or maintain adequate lumbar perfusion:

- Thoracoabdominal aorta vascular reconstruction.
- Pseudotumor cerebri.
- Hydrocephalus.

Providing therapeutic administration of medications not otherwise attainable by intravenous or other routes:

- Antibiotics or chemotherapy.
- Analgesics.
- Contrast or nuclear medicine substrates for myelogram or cisternogram.

23.3 Contraindications

- Increased intracranial pressure with:
  - Cerebral herniation or impending herniation from either intracranial or epidural mass.
    Obtain a non-contrast head CT to rule this out prior to puncture.

23.4 Relative Contraindications

- Increased ICP with focal neurologic signs.
- Severe osteoarthritis, degenerative disease, lumbar spine fractures, or prior lumbar surgery.
- Coagulopathy:
  - Obtain history for liver disease, anticoagulant, or antiplatelet use.
  - Obtain CBC, platelet count, and PT/INR, PTT (lumbar puncture is contraindicated if platelet counts are <50,000 or INR >1.4).
- Infection near the lumbar puncture site.

23.5 Preparation

Equipment (Fig. 23.2):

- Local anesthesia (1% lidocaine without epinephrine).
- Sterile gloves, sterile fenestrated drape.
- Betadine or chlorhexidine skin preparation.
- Spinal needle (22 gauge, 3.5 in. in adults; 1.5–2.5 in. in children).
- Three-way stopcock.
- Manometer.
- Four specimen tubes.

The spinal needle has a beveled tip and stylet which serves as an introducer and provides additional support to the needle (Fig. 23.3a, b). A close-up of the spinal needle demonstrates the beveled nature of the needle (Fig. 23.4).

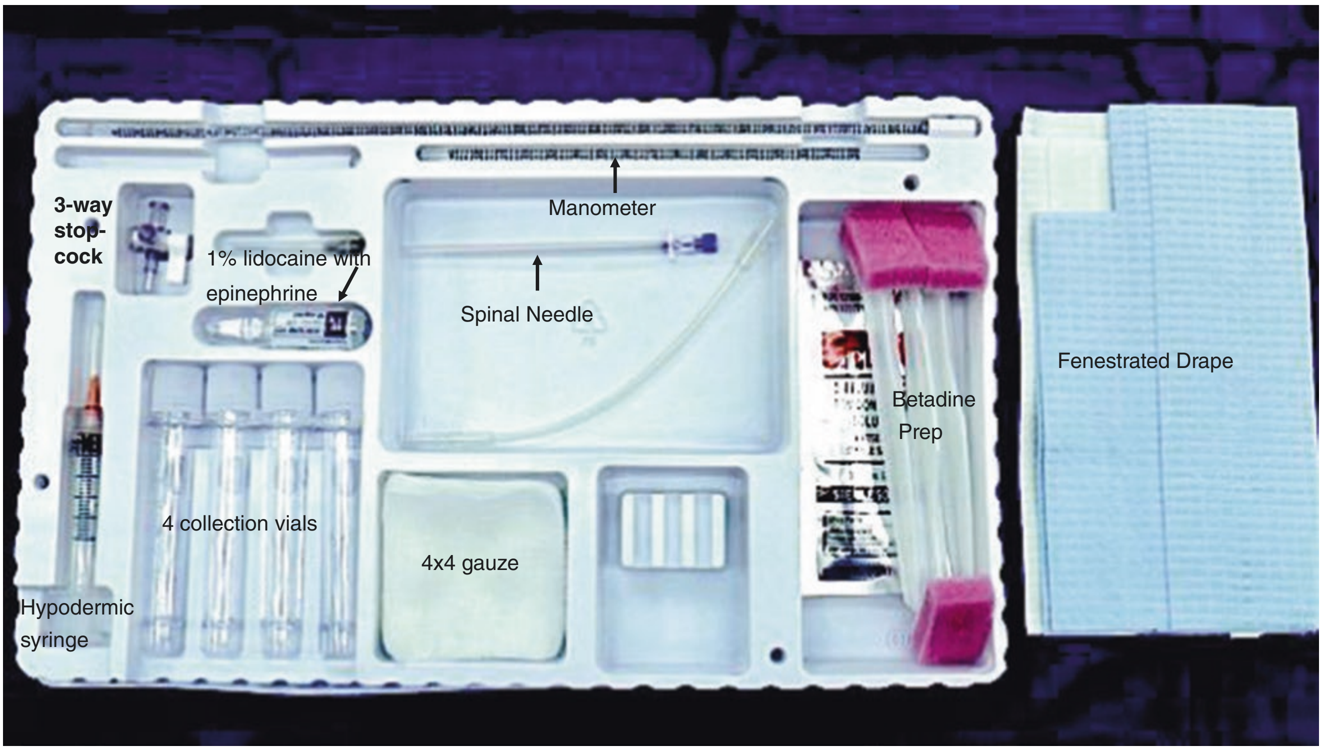


Fig. 23.2 Representative lumbar puncture kit. Essential items include Betadine or chlorhexidine preparation with sponges, sterile drape, 1% lidocaine without epinephrine, hypodermic syringe, spinal needle, three-way stopcock, IV tubing, manometer, and four collection vials

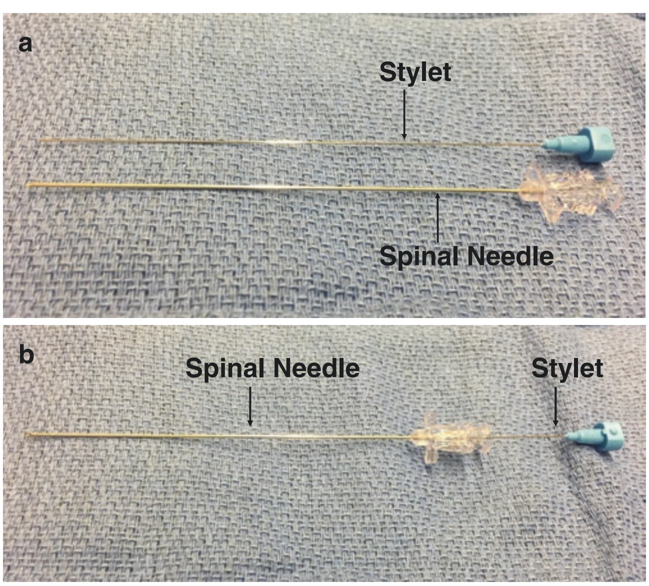


Fig. 23.3 (**a**) Spinal needle and stylet arranged side by side. (**b**) Stylet inserted into spinal needle

Fig. 23.4 Close-up of the beveled tip of a spinal needle

23.6 Technique

Proper positioning is essential to the success of the lumbar puncture.

The procedure should be performed under full sterile precautions, including full body draping, gown, mask,and sterile gloves.

Lateral decubitus position (preferably with the left side down):

- The patient is placed in the fetal position (flexed head, neck, back, and limbs). The legs should be parallel to each other. A pillow may be placed under the head for patient comfort (Fig. 23.5a, b).
- Palpate the iliac crest (L4).
- Palpate and mark the L3–L4 or L4–L5 interspace (in obese individuals this may be difficult). Access between L4 and L5 is recommended to avoid puncturing the cord (conus medullaris), which terminates at L1–L2 in adults (Fig. 23.6).
- Apply sterile preparation with Betadine or chlorhexidine.
- Apply a fenestrated sterile drape (Fig. 23.7).
- Inject 1% lidocaine without epinephrine into the subcutaneous tissues with a 2–3 cc syringe to create a wheal.
- Insert the spinal needle between L4 and L5, pointing the needle cephalad. Appreciate the "pop" and giving sensation as the needle passes through the dura (Fig. 23.8a).
- Slowly withdraw the stylet, monitoring for cerebrospinal fluid flow, which confirms the correct position of the needle (Fig. 23.8b).
- Steady the spinal needle and remove the trocar or stylet slowly to achieve the following:
  – Attach a three-way stopcock and then a manometer to check for opening pressures. The manometer will screw in via luer-lock connection. Hold the system vertical and monitor the column of fluid, noting where it achieves steady state (Fig. 23.9a, b). Remove the manometer and assess for backflow of fluid.
  – Collect CSF fluid—four bottles. Note consistency and color of CSF as it drains. A "bloody" tap in the absence of subarachnoid hemorrhage should resolve with continued drainage of CSF from the first to fourth vial (Fig. 23.10).
  – Infusion or drainage catheters may be inserted using Seldinger technique.
  – Reinsert the stylet prior to removing the spinal needle.
  – Cover the puncture site with a sterile dressing.

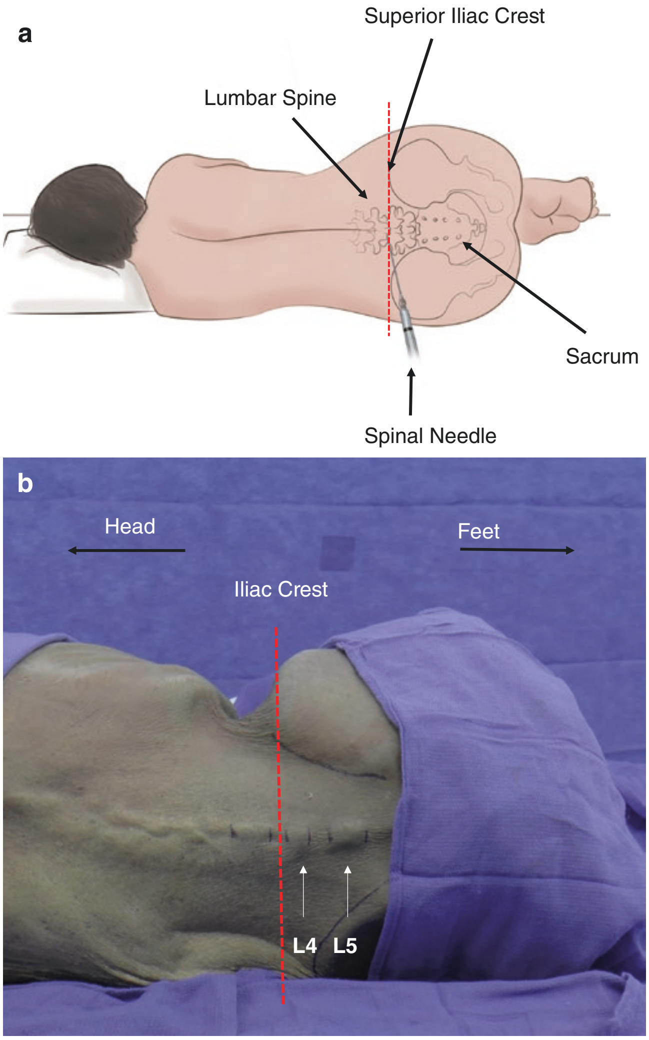


Fig. 23.5 (**a**) Patient in the left lateral decubitus position with the knees and head flexed toward the chest. The superior iliac crest is as shown and is an important landmark that correlates with the L4 level. (**b**) Patient in the left lateral decubitus position with the knees and head flexed toward the chest. L4 and L5 are marked; the superior iliac crest is as shown and is an important landmark that correlates with the L4 level

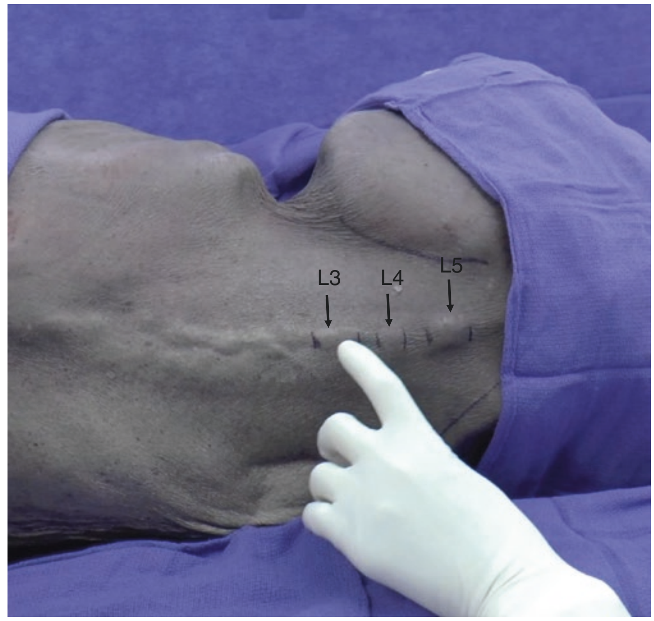


Fig. 23.6 Palpate and mark the L3–L4 or L4–L5 interspace (in obese individuals this may be difficult). Access between L4 and L5 is recommended to avoid puncturing the cord (conus medullaris), which terminates at L1–L2 in adults

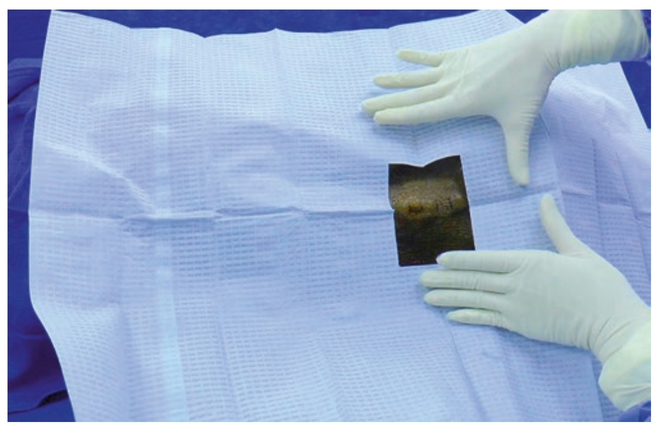


Fig. 23.7 Apply a fenestrated sterile drape

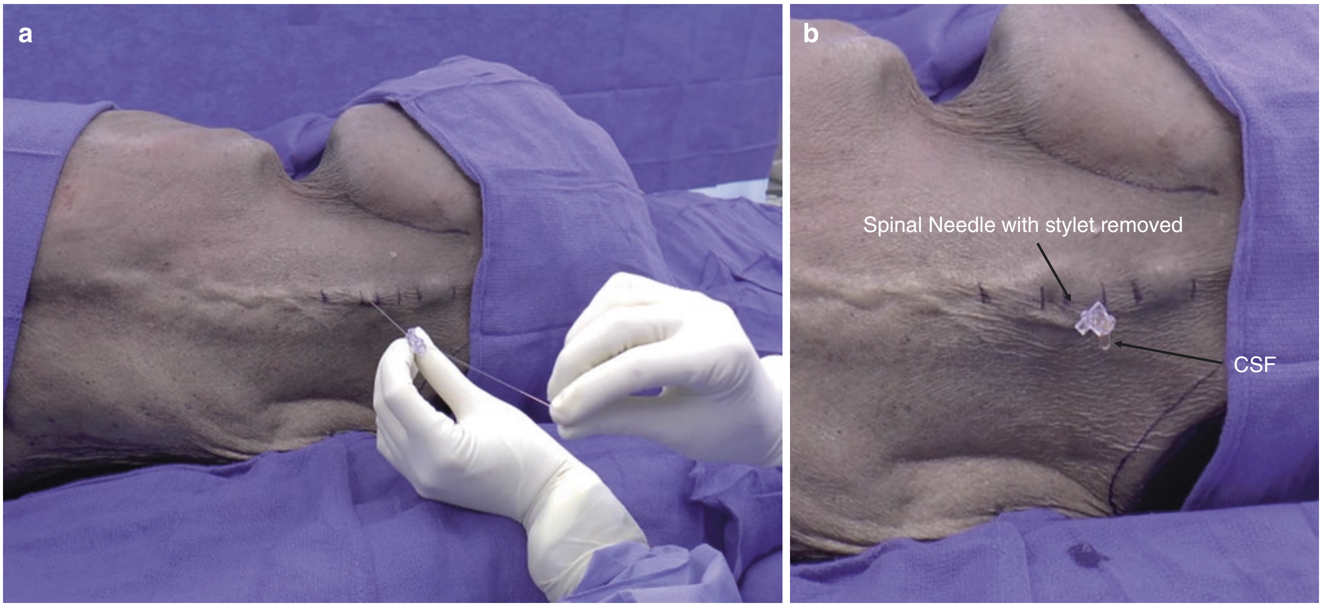


Fig. 23.8 (**a**) Insert the spinal needle between L4 and L5, pointing the needle cephalad. Appreciate the "pop" and giving sensation as the needle passes through the dura. (**b**) Slowly withdraw the stylet, monitoring for cerebrospinal fluid flow, which confirms the correct position of the needle

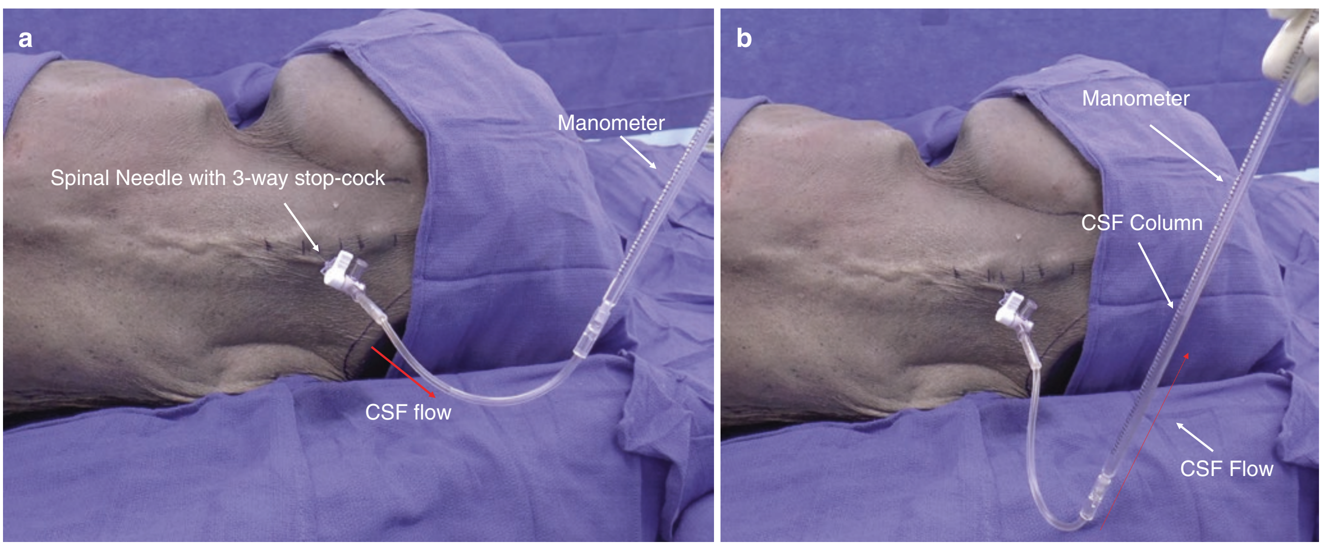


Fig. 23.9 (**a**, **b**) Attach a three-way stopcock and then a manometer to check for opening pressures. The manometer will screw in via luer-lock connection. Hold the system vertical and monitor the column of fluid, noting where it achieves steady state

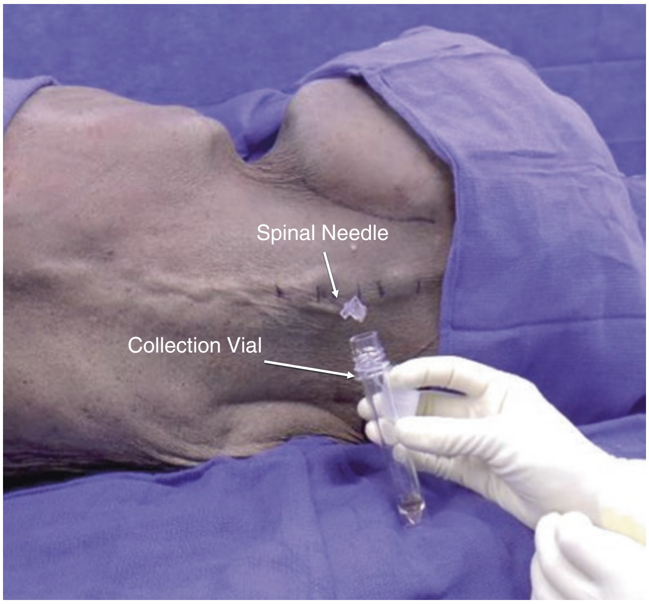


Fig. 23.10 Collect CSF fluid—four bottles. Note consistency and color of CSF as it drains. A “bloody” tap in the absence of subarachnoid hemorrhage should resolve with continued drainage of CSF from the first to fourth vial

23.7 CSF Investigations

- Note gross appearance of the CSF (cloudy, clear, bloody).
- Cytology: number and type of cells.
- Protein and glucose content.
- Gram stain for bacteria and separate fungal, mycobacterial cultures, PCR (i.e., bacterial or viral meningitis).
- Gamma globulin and oligoclonal bands (in multiple sclerosis).

23.8 Risks/Complications

- Transtentorial herniation: this is the most serious complication and is usually fatal. It may occur in patients with increased intracranial pressure. A non-contrast CT of the head should be obtained in patients with suspected intracranial hypertension before lumbar puncture in order to rule out mass lesions or other conditions associated with intracranial hypertension.
  - Monitor for change in neurologic status, such as asymmetric or sluggish pupillary reflexes.
- Infection.
  - Monitor for persistent fevers, seizures, photophobia, and headache and symptoms and signs concerning for meningitis.
- Bleeding.
  - If the tap is bloody, continue to monitor. Early initiation of anticoagulation may need to be held until resolution.
- Spinal “headache” or backache.
- Persistent CSF leak.
- Nerve injury, paralysis.
  - Often with paresthesias in L4/L5 distribution; if lower, investigate for urinary or stool incontinence and/or saddle anesthesia. Patients rarely present with flaccidity, and as such, one should be vigilant for an expanding hematoma.

23.9 Pitfalls

- Obese or muscular patients with thick subcutaneous wall
  - Ensure proper positioning by straightening out the spine. This may require propping of pillows underneath the left or right lateral chest wall and an additional towel roll under the axilla for stability.
    Palpate and mark both iliac crests.
    Palpate the bony prominences of L4/L5 (most prominent).
    If not successful, reattempt with patient sitting up, hands resting on the knees or flat surface at or below the level of the elbows to allow the lumbar spine to straighten the lordosis of the spine.
- Not able to access subarachnoid space (i.e., degenerative spine disease, radiation):
  - Replace stylet into needle and advance slowly by 2–3 mm, remove stylet, and check for CSF.
  - Angle the needle slightly cephalad.
  - Remove the stylet slowly to avoid "suction effect" of cauda fibers.

24 Neuraxial Analgesia in the ICU: Epidural and Paravertebral Blocks

Adam Penman, Sanaz Ghaffari, and Michel Kearns

24.1 General Principles

- The epidural space surrounds the dura and contains fat, lymphatics, blood vessels, connective tissue, and nerve roots (primary site of action for local anesthetics).
- When compared to the dense motor and sensory blockade of a spinal injection, epidural catheters provide controlled segmental analgesia spanning 2–3 spinal cord levels above and below level of insertion, with minimal motor blockade.
- Achieving desired sensory blockade level depends on the type, concentration, and volume of local anesthetic solution.
- Advantages of neuraxial analgesia include (1) minimizing parenteral opioids and their associated complications, (2) decrease rate of nosocomial pneumonia, and (3) shorter duration of mechanical ventilation in patients with rib fractures.
- Spinal and/or epidural hematoma, as a result of catheter insertion or removal, is a rare but potentially devastating complication in the context of coagulopathy or patients taking anticoagulant medication.
- Any patient with relative contraindications or complications should receive prompt consultation with an anesthesiologist or a member of the acute pain management team.
- Epidural catheter placement should only be performed by those with the technical expertise and a substantial amount of experience in the placement of this regional anesthesia technique.
- Paravertebral blockade has become more prevalent in the ICU, especially for pain associated with unilateral rib fractures, breast surgery, and thoracic surgery.
  - The success rate and analgesic efficacy of paravertebral blocks are similar when compared to thoracic epidural catheter placement.
  - Compared to epidural analgesia, paravertebral blockade is safer to perform and results in less hypotension and urinary retention.

A. Penman · S. Ghaffari · M. Kearns (✉)
University of Southern California, Los Angeles, CA, USA
e-mail: michel.j.kearns.mil@mail.mil

24.2 Indications

- Musculoskeletal trauma, especially multiple rib fractures.
- Acute postoperative pain management in patients undergoing:
  - Thoracic or abdominal surgery.
  - Vascular and orthopedic procedures of the pelvis and lower limb.
  - Pain associated with acute pancreatitis.
  - Pain associated with malignancy.

24.3 Absolute Contraindications

- Allergy to amide or ester local anesthetic.
- Local infection at the insertion site.
- Elevated intracranial pressure (ICP).
- Uncorrected hypovolemia.
- Bleeding diathesis.

24.4 Relative Contraindications

- Sepsis.
- Thrombocytopenia.
- Coagulopathy (INR > 1.5).
- Spine trauma/instability, anatomic abnormalities, history of spine surgery.
- Uncooperative patient (unable to position).
- Neurologic disease (e.g., multiple sclerosis, etc.).
- Severe aortic/mitral stenosis.

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_24

24.5 Technique of Epidural Catheter Placement

24.5.1 Positioning

- Epidural catheter insertion can be performed in the lateral decubitus or sitting position.
- The patient must be cooperative in order to optimize positioning for successful placement. Inability to place the patient in a suitable position is a relative contraindication.

24.5.2 Surface Anatomy

- Once the patient is positioned, identify the appropriate vertebral level to place the block, per the table below:

Location of operation	Vertebral placement level
Thoracotomy	T4–T6
Upper abdomen	T8
Lower abdomen	T10–T12
Lower extremity/pelvis	L2–L4

- Anatomic landmarks help to identify the appropriate vertebral level (Figs. 24.1 and 24.2):

Anatomic landmark	Associated vertebral level
Superior aspect of iliac crests (not shown)	L4–L5 interspace
Inferior border of the scapula	T7 spinous process

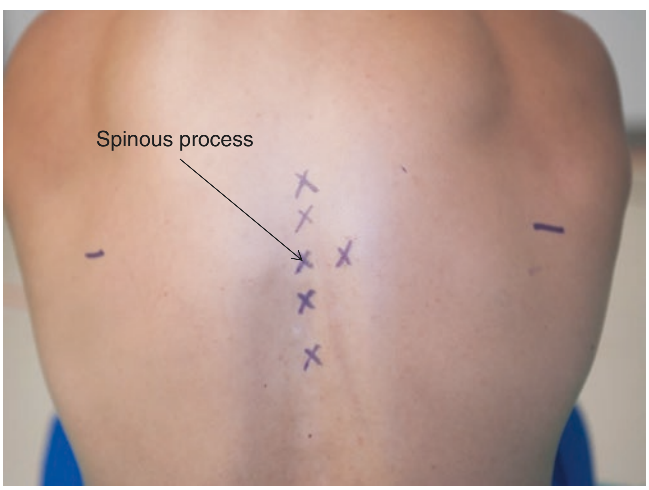


Fig. 24.1 Showing the sitting position with flexion of spine and denoted thoracic spinous processes

24.5.3 Procedure

Epidural catheter placement should only be performed either by or under the direct supervision of a physician with the technical expertise and experience with this procedure.

Fig. 24.2 Demonstrating the inferior border of the scapula (straight line) as it approximates the level of the T7 spinous process (middle "X" mark)

- Perform pre-procedure pause.
- Offer the patient reassurance and administer sedative medication as indicated.
- Place the patient in either sitting or lateral decubitus position and disinfect the field.
- Follow sterile precautions while performing this procedure.
- Don a cap and mask. Prepare the epidural kit, to include sterile gloves, chlorhexidine applicator, sterile drape, 3-cc and 5-cc syringe, 21-gauge needle, glass syringe, Tuohy needle with stylet, sterile saline, local anesthetic, catheter filter, epidural catheter with cap, gauze, and label (Figs. 24.3 and 24.4).
- Apply sterile gloves and place the fenestrated drape on the patient's disinfected back.
- Infiltrate an adequate amount of local anesthetic in the skin and subcutaneous tissue.
- Insert the Tuohy needle midline into the anesthetized skin over the interspinous space and carefully advance through the subcutaneous tissue.
- The needle will penetrate the supraspinous and interspinous ligaments and engage the ligamentum flavum, characterized by a change in tactile sensation of the needle tip (see image below) (Fig. 24.5).
- The epidural space is identified using the loss-of-resistance (LOR) technique utilizing the frictionless glass syringe. *Note: a bracing position should be adopted by the non-dominant hand to control forward advancement of the needle, as per the image below* (Fig. 24.6):
- Once the epidural space is entered, a catheter is advanced through the Tuohy needle into the epidural space, to a distance of approximately 4–6 cm past the needle tip.
- The catheter is tested for intravascular or intrathecal placement, both of which require replacement.
  - Aspiration: sanguineous aspiration suggests an intravascular catheter.

Fig. 24.3 Typical contents found in an epidural or paravertebral catheter kit including sterile gloves and drape, Tuohy needle and catheter, the loss-of-resistance syringe, and a syringe for subcutaneous infiltration of local anesthetic

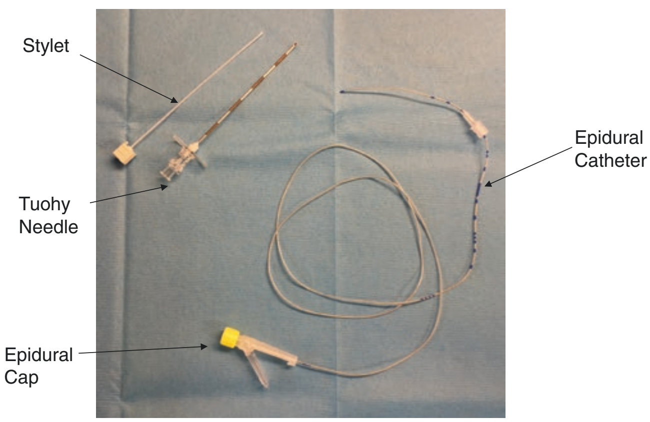


Fig. 24.4 Epidural catheter and Tuohy needle with stylet (removed)

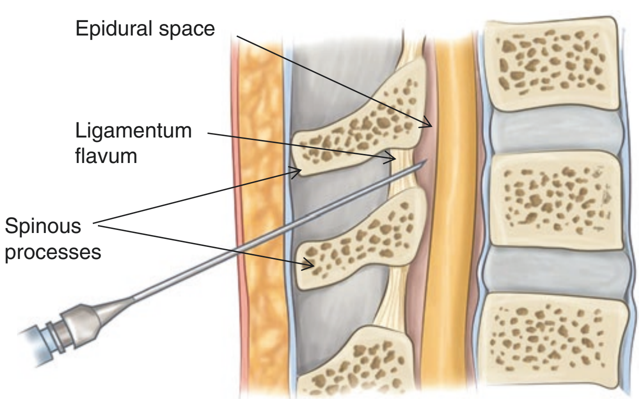


Fig. 24.5 The needle enters the epidural space between the spinous processes and through the ligamentum flavum. Loss of resistance is detected upon the needle tip entering the epidural space

Fig. 24.6 Bracing position to stabilize the needle while inserting into the epidural space and feeling for loss of resistance

  – Test dose: low-concentration local anesthetic containing epinephrine 1:200,000 is injected through the catheter.
    If the catheter is intrathecal, the patient may report brisk and complete anesthesia below the level of the epidural block (spinal anesthesia).
    If the catheter is intravascular (despite a negative aspiration), the epinephrine will cause an increase in heart rate.
- The catheter is capped to maintain sterility and secured in place. An infusion pump may be attached to the catheter to provide continuous epidural analgesia with local anesthetic and/or opioid medication.

24.5.4 Complications

During the procedure		
Reaction	Symptoms	Treatment
Vagal reaction	Hypotension, syncope	Pause procedure until resolved, place supine
Dural puncture ("wet tap")	CSF pouring from epidural needle	Remove needle *may* cause PDPH
Intravascular injection	AMS, cardiac instability	ACLS, intralipid (10–30% fat emulsion), supportive care
Intrathecal injection	AMS, cardiac instability	ACLS, supportive care
Spinal cord injury	Pain, numbness, weakness	Remove needle and obtain expert consultation

Immediately following the procedure		
Reaction	Symptoms	Treatment
Sympathectomy	Hypotension, bradycardia, nausea	Fluid administration, vasopressors, reduce/remove local anesthetic
Neurological deficit	Various	Expert consultation, rule out epidural/spinal hematoma

Hours to days following the procedure		
Reaction	Symptoms	Treatment
Backache	Mild, self-limited, no neurological deficits	Warm/cold compress, acetaminophen, NSAIDs
Pruritus	Itchiness	Opioid antagonist
Urinary retention	Abdominal pain or pressure	Continuous/intermittent catheterization
Ineffective analgesia	Persistent pain	Change patient position, adjust infusion, replace epidural
Dense motor blockade	Profound weakness	Reduce/remove local anesthetic
Post-dural puncture headache (PDPH)	Headache; improves when moving from standing to supine	Recumbent positioning, analgesics, fluid administration, caffeine, epidural blood patch
Spinal/epidural hematoma	Sharp back/leg pain, motor weakness, sphincter dysfunction	CT, MRI, expert consultation
Epidural abscess	Back pain, radicular pain, neurological deficits	Remove catheter, culture catheter tip, wide spectrum antibiotics, CT/MRI, expert consultation
Meningitis/arachnoiditis	Pain, neurological deficits, AMS	Remove catheter, culture catheter tip, wide spectrum antibiotics, CT/MRI, expert consultation

24.5.5 Catheter Removal

- Catheter removal must be coordinated with anticoagulation administration to avoid spinal/epidural hematoma.
- The patient should have a normal coagulation profile and a platelet count >100,000.
- Confirm that the catheter tip is intact after removal. If the tip of the catheter is not intact after removal, sheering or fragmentation of the catheter has likely occurred. Retained fragments are sterile and unlikely to cause neurological sequelae and therefore can be left in place. Imaging should be obtained to locate the fragment, and exploratory laminectomy should be considered if the patient develops neurologic changes.

Sheering of an epidural catheter	
Location	Treatment
Epidural space	Observation
Superficial tissues	Surgical excision

24.6 Technique of Paravertebral Neuroanalgesia

24.6.1 Paravertebral Single-Shot Injection and Catheter Insertion

- Paravertebral blockade has become more prevalent in the ICU (especially for pain associated with unilateral rib fractures, breast surgery, and thoracic surgery) due to improvements in ultrasound technology and less stringent anticoagulation restrictions.
- The paravertebral block is performed by injecting or infusing a local anesthetic solution into the *paravertebral space*.
- The *paravertebral space* is extradural but does communicate with the epidural space. Its boundaries are the vertebral bodies, parietal pleura, and transverse processes. The space contains blood vessels, the sympathetic chain, communicating rami and spinal nerves as they emerge from the intervertebral foramina (primary site of action of local anesthetic) (Fig. 24.7).
- Injection of a local anesthetic solution into the paravertebral space produces ipsilateral, multi-dermatomal somatic, and sympathetic nerve blockade.
- The success rate and analgesic efficacy of paravertebral blocks are similar when compared to thoracic epidural catheter placement.
- **Advantages**
  - Less hypotension

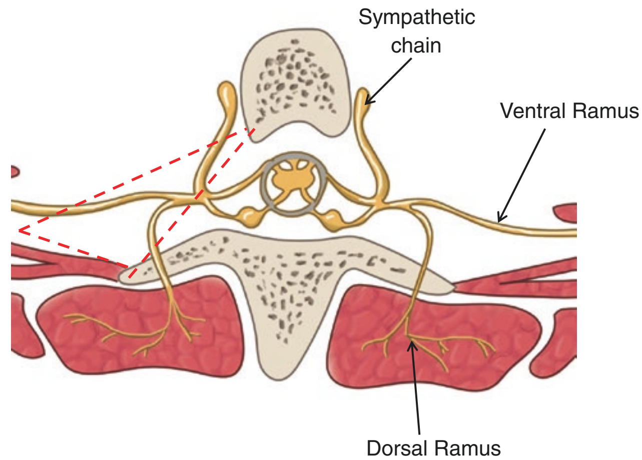


Fig. 24.7 Showing a cross-sectional view of the thoracic spine with the paravertebral space (red-dashed triangle)

  - No motor blockade
  - Less urinary retention
  - Reduced risk of neurological injury
- **Disadvantages**
  - Unpredictable dermatomal spread
  - Less visceral pain coverage
  - Only unilateral coverage
- **Complications**
  - Pneumothorax
  - Local anesthetic toxicity
  - Bilateral block (epidural spread)
  - Horner's syndrome (miosis, partial ptosis, anhidrosis)

Part VI

Compartment Syndromes

Extremity Muscle Compartment Pressure Measurement

25

Caroline Park, Damon Clark, and Demetrios Demetriades

25.1 General Principles

- The normal muscle compartment pressure is <8 mmHg. Acute increase of the compartment to >20–30 mmHg results in compartment syndrome, which reduces the capillary perfusion and results in muscle and nerve ischemia.
- An absolute muscle compartment pressure of >30 or 40 mmHg is considered by many surgeons as a surgical emergency. An alternative to the absolute compartment pressure is the compartment perfusion pressure (CPP), as calculated by:
  - CPP = diastolic pressure—compartment pressure.
  - CPP of <30 mmHg indicates decreased perfusion and is a surgical emergency.
- Decreased arterial inflow compromises tissue perfusion, which results in muscle and nerve ischemia. Reversible muscle ischemia and neuropraxia may occur in patients with up to 4–6 h of compartment syndrome. Irreversible neuromuscular damage usually occurs after 6 h of ischemia.
- The variables affecting the severity of the compartment syndrome include hypotension, compartment pressure, duration of elevated compartment pressure, perfusion pressure, and individual susceptibility.
- Delayed treatment of compartment syndrome results in muscle necrosis, myoglobinemia, myoglobinuria, and acute renal failure. Locally, it can result in muscle contracture, sensory deficits, paralysis, and possibly amputation.
- CPK levels higher than 5000 U/L are associated with high risk of acute kidney injury. These patients should be treated with generous fluid administration to produce UOP >100 mL/h, and administration of bicarbonate and mannitol in more severe cases. One should have a low threshold to treat with fasciotomy in these cases.

C. Park · D. Clark · D. Demetriades (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

- The anterior and lateral lower leg compartments are the most likely to develop compartment syndrome. The flexor compartment of the forearm is the next most common site.

25.2 Etiology

- Extremity compartment syndrome may occur in traumatic and non-traumatic conditions:
  - Traumatic conditions:
    Severe long-bone fractures.
    Crush injury.
    Ischemia due to arterial injury, ligation, or thrombosis of a major extremity vein.
    Circumferential burns.
    In rare occasions, massive fluid resuscitation in trauma or burn patients may cause secondary compartment syndrome.
    Snake or spider bites.
  - Non-traumatic conditions:
    Unconscious or obtunded patients due to severe drug or alcohol intoxication and prolonged limb compression.
    Injection of illicit drugs.
    Bleeding diathesis or pharmacological anticoagulation with spontaneous bleeding in a muscle compartment.
    Severe deep venous thrombosis.
    Necrotizing myositis.
  - Iatrogenic conditions:
    Constricting bandages or casts, pelvic binders, tight casts.
    Accidental extravasation of intravenous fluids (i.e., malpositioned intraosseous catheter).
    Prolonged general anesthesia in morbidly obese patients (buttock compartment syndrome).

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_25

Prolonged limb compression due to poor positioning during surgery.

Prolonged limb ischemia during vascular procedures (monitor for reperfusion syndrome) or after placement of intra-aortic balloon pump.

Young males are most likely to develop extremity compartment syndrome because of larger muscle mass. In rare occasions, athletes completing long-distance races may develop lower extremity compartment syndrome.

25.3 Diagnosis: Clinical Signs

- A high index of suspicion among patients at risk is the cornerstone of early diagnosis.
- The diagnosis of compartment syndrome is based on the history, clinical examination, lab findings, and measurement of compartment pressures.
- Clinical examination is often not reliable, especially if performed by an inexperienced physician.
- Serial clinical examinations, lab tests, and compartment pressure measurements may be needed when the clinical diagnosis is not definitive.
- The diagnosis can be difficult in unevaluable patients, such as in patients with head injuries or patients sedated on mechanical ventilation.

The six Ps described in extremity compartment syndrome (pain, paresthesia, pressure, pallor, pulselessness, paralysis) are not always present. Some of these are very late findings, when the extremity becomes non-salvageable.

- Pain out of proportion, often not responding to narcotic analgesics. The pain becomes much worse with passive stretch of the involved muscles. Pain is the most common and earliest clinical finding. However, it might be difficult to elicit in unevaluable, obtunded, or critically ill patients.
- Paresthesia is a fairly early sign, indicating nerve ischemia.
- Pressure (tense compartment on palpation): not a reliable finding.
- Pallor (late sign).
- Pulselessness (late sign).
- Paralysis (late finding).

25.4 Diagnostic Tests

- CPK levels are always elevated and indicate muscle damage. Very high levels are suggestive of large muscle compartment involvement (i.e., gluteal, thigh compartments).
- Elevated creatinine, BUN, and potassium may be present in later stages of muscle ischemia.
- Myoglobinemia and myoglobinuria result in "red" urine but no hematuria on microscopic urinalysis.
- Pulse oximetry is not useful in the early diagnosis of compartment syndrome. Abnormal SaO_2 is a very late finding.
- Measurement of muscle compartment pressures is a reliable test and should be considered liberally.

25.5 Measurement of Compartment Pressures

- Compartment pressures should be measured if there is a clinical suspicion of compartment syndrome, but the definitive diagnosis is uncertain.
- Pressures should be measured in *all* muscle compartments of the involved limb. It is possible that one compartment is normal, while the adjacent one has high pressures.
- The pressures can be measured with a handheld device (i.e., Stryker® device) or by connecting an 18 gauge needle placed in the muscle compartment to a pressure transducer. With both techniques, side-port needles are more accurate at measuring the pressure than regular needles (Figs. 25.1 and 25.2).

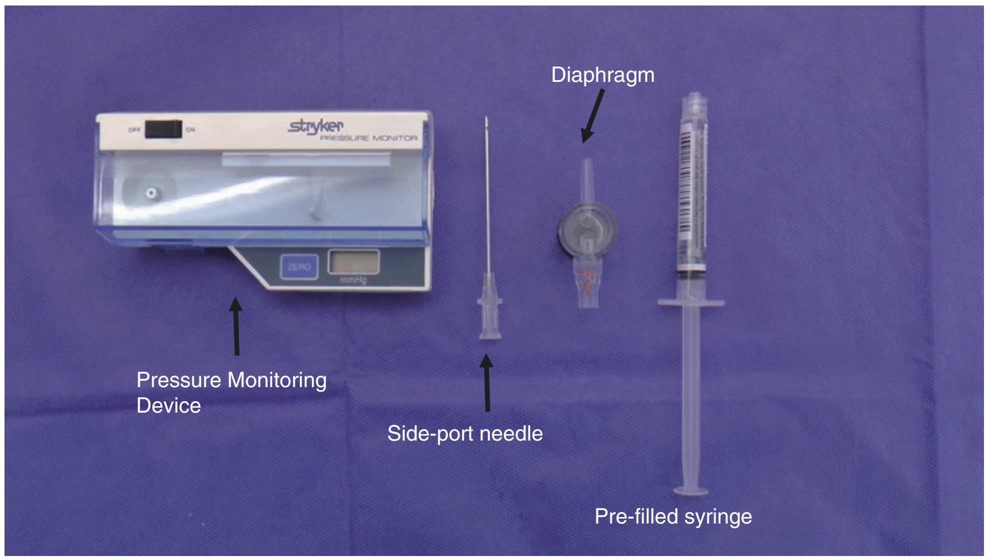


Fig. 25.1 Equipment for pressuring monitoring by a handheld device. The device shown here is a Stryker® pressure monitor. Other required elements include a prefilled syringe, diaphragm chamber, and side-hole needle

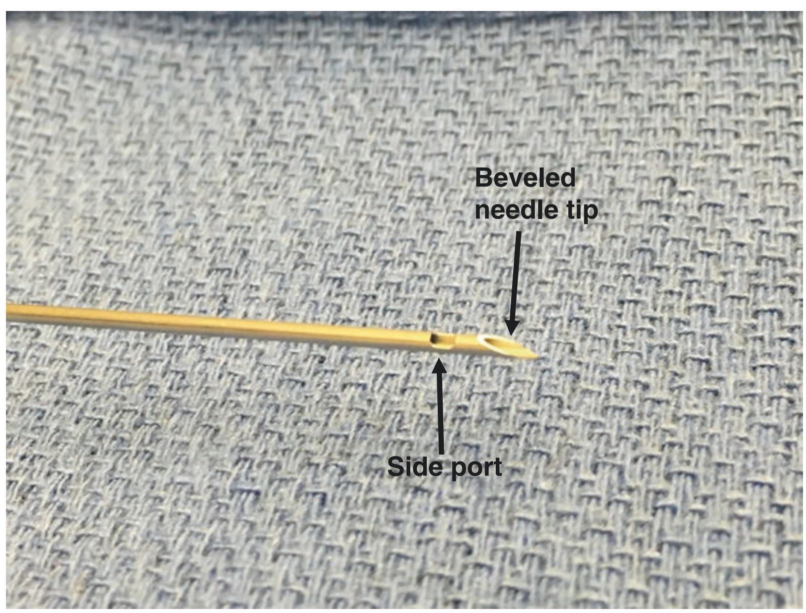


Fig. 25.2 Close-up of side-port and beveled point of a needle used for transducing pressure

25.6 Technique of Compartment Pressure Measurement with Stryker Device

1. Assemble the device by connecting the side-port needle (A) to the diaphragm chamber (B) and the diaphragm to the prefilled syringe (C). Gently flush 0.5–1 cc of saline through the unit to flush out any residual air of the system (Fig. 25.3a–c).
2. Insert the assembled system into the device and snap close without forcing it.
3. Turn on the unit (upper outer corner).
4. Push the "zero" button down (next to reading display), and wait for a few seconds until it shows zero. Identify appropriate landmarks (see below for separate compartments). Insert the needle perpendicular to the skin and insert into the muscle compartment (Fig. 25.4).
5. Slowly inject 0.3 mL into the compartment.
6. Wait for a few seconds for the display to reach equilibrium before reading the pressure.
7. Keep unit steady as pressure is monitored for the next several seconds. Note the pressure in the reading display (Fig. 25.5).

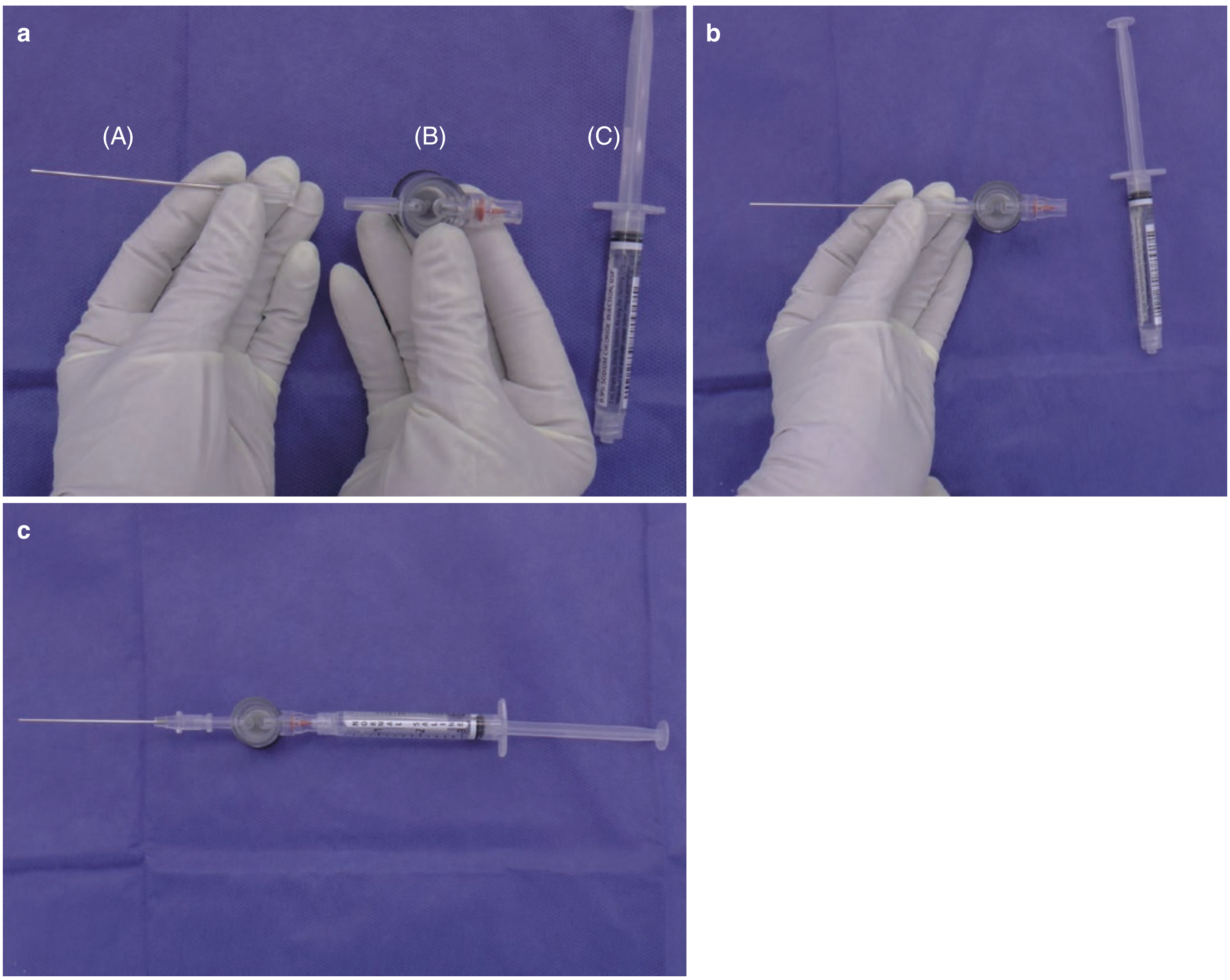


Fig. 25.3 (**a**) Connect the diaphragm (B) to the side-port needle (A). (**b**) Connect the assembled needle and diaphragm device to a 3 cc prefilled syringe. (**c**) Assembled needle, diaphragm, and syringe. Gently flush 0.5–1 cc of saline through the unit to flush out any residual air of the system

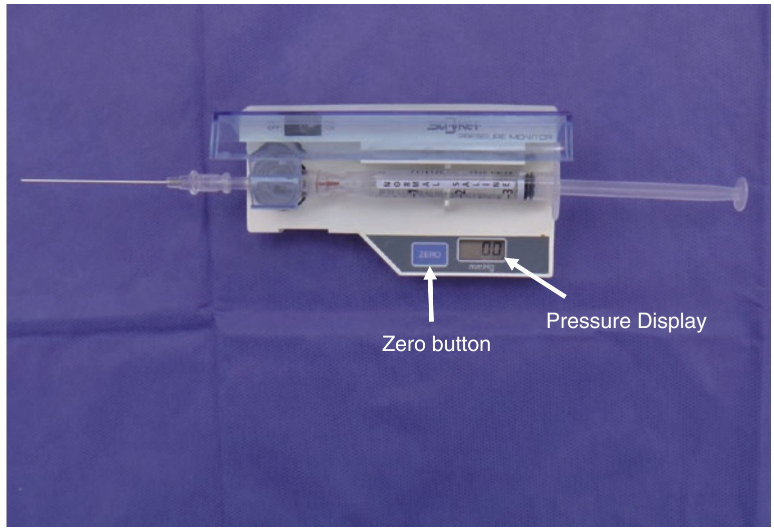


Fig. 25.4 Assembled system (cover lifted for illustrative purposes). Device is on and "zero" button pushed; display shows "00," preferably at the level and angle that the device will be used

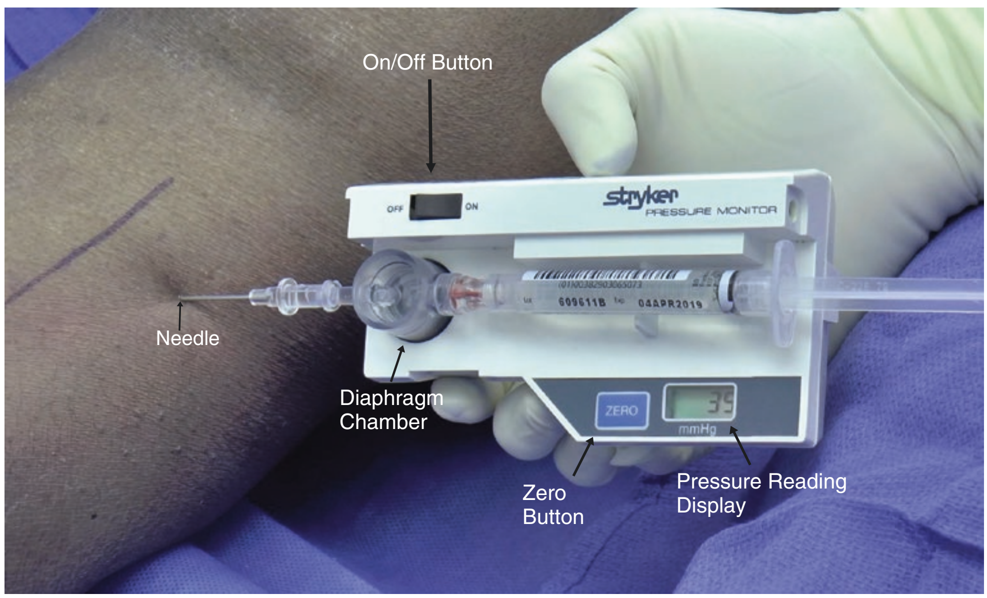


Fig. 25.5 Slowly inject 0.3 mL into the compartment at a perpendicular angle, and wait for a few seconds, and keep the unit steady while it reaches equilibrium

25.7 Technique of Compartment Pressure Measurement with Angiocatheter and Pressure Transducer

25.7.1 Setup

Connect an empty 10 cc syringe to three-way stopcock and arterial line tubing to 16 or 18 g angiocatheter. With the stopcock in the “off” position 180° from the angiocatheter (away from syringe and patient), withdraw sterile saline until the angiocatheter and tubing are filled with saline.

25.7.2 Calibrate

Set up arterial line tubing with pressure transducer, and make sure that it is level with the compartment of interest to avoid under- or over-reading. Prime the line with sterile saline, and connect to the three-way stopcock with the “off” position opposite of the syringe so the system is open.

Insert the angiocatheter into the compartment of interest. Gently push down on the syringe plunger to instill 1–3 cc of fluid into the compartment, and monitor the column of fluid in the tubing (with elevated pressures, the column would drift away from the patient), and wait several seconds to record the compartment pressure transduced from the arterial line tubing.

25.8 Muscle Compartments and Site of Needle Insertion

- Good knowledge of the anatomy and landmarks of the extremity muscle compartments is essential to the execution of compartment pressure monitoring.
- In assessing for possible compartment syndrome, the pressures should be measured in all compartments of the involved extremity.
- Proper needle placement into the compartment can be confirmed by digital compression of the specific compartment. This maneuver results in a major increase of the pressure reading.

25.9 Upper Extremity

25.9.1 Arm

- The upper arm has two compartments: anterior and posterior. Medially, the brachial artery lies between the two compartments (Fig. 25.6a,b).
- Keep the arm in neutral position. Excessive flexion or extension at the elbow can affect compartment pressures.
- For anterior compartment pressures, insert the needle perpendicular to the skin, in the middle third of the anterior arm (Fig. 25.7a,b).
- For posterior (extensor) compartment pressures, insert the needle in the middle third of the posterior arm. The medial aspect of the upper arm should be avoided when checking compartment pressures given the path of the axillary and brachial arteries and median and ulnar nerves (Fig. 25.8a,b).

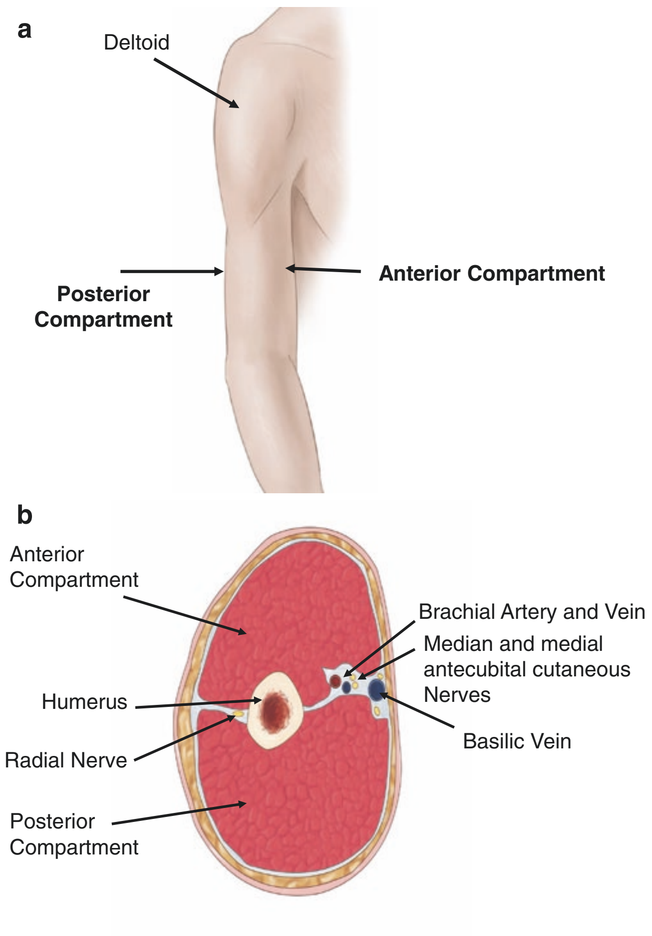


Fig. 25.6 (**a**, **b**) Cross-sectional view of the upper arm and its two muscle compartments. The anterior and posterior compartments are illustrated here in relation to the humerus, brachial artery and vein, basilic vein, and median nerve.

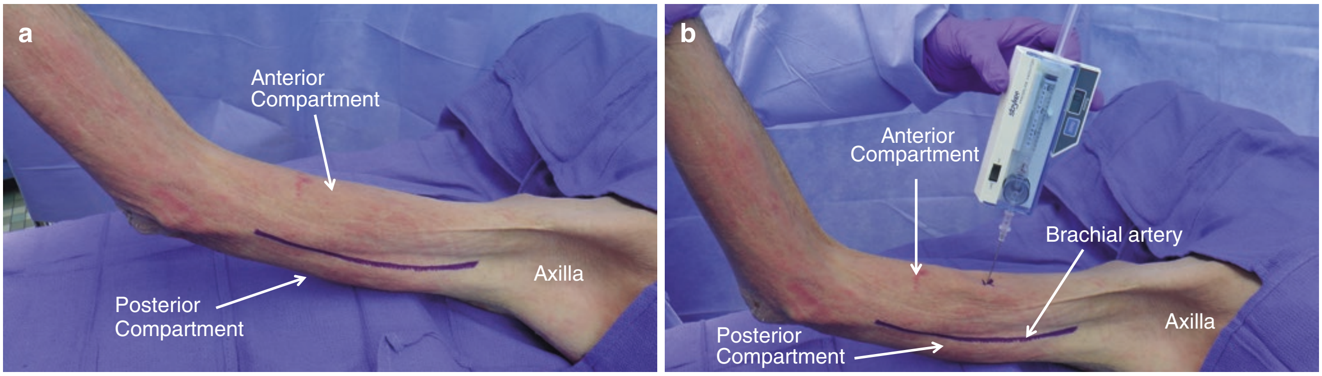


Fig. 25.7 (**a**, **b**) The upper arm has two compartments (anterior and posterior), divided by an intermuscular septum and the brachial artery. To check anterior upper arm compartment pressures, insert the needle perpendicular to the skin in the middle third of the anterior arm.

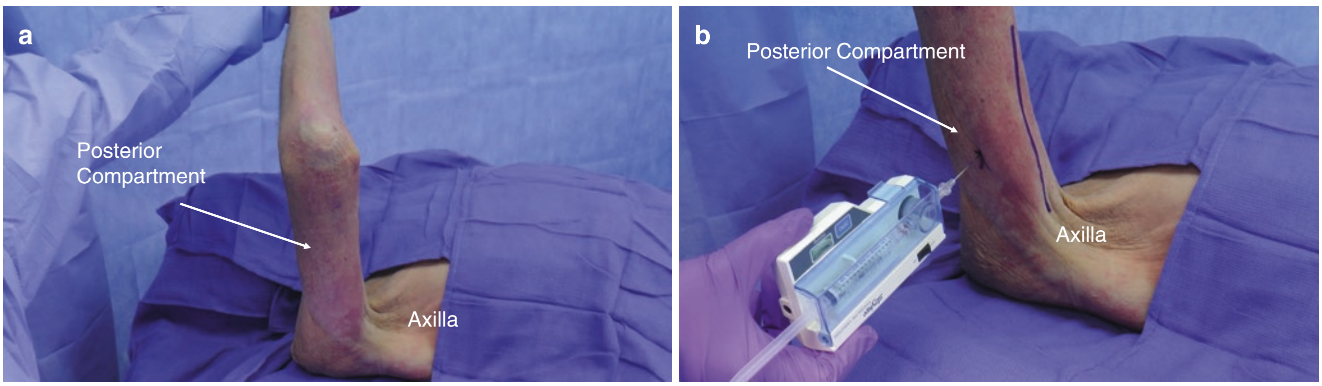


Fig. 25.8 (**a**, **b**) To measure the posterior compartment of the upper arm, raise the arm, and gently flex the forearm at the elbow to avoid overextension and exaggeration of posterior compartment pressures. Insert the needle perpendicular to the skin at the junction between the first and second third of the upper arm.

25.9.2 Forearm

- The forearm has three compartments: volar (flexor), dorsal (extensor), and lateral (mobile wad). The mobile wad is often grouped with the dorsal compartment (Fig. 25.9).
- Keep the forearm in neutral position. Excessive flexion or extension at the wrist can affect compartment pressures.
- The flexor compartment is the most common forearm compartment to develop the compartment syndrome. For pressure measurements, insert the needle perpendicular to the skin in the middle third of the flexor surface of the forearm (Fig. 25.10a,b).
- For dorsal (extensor) compartment pressure measurements, insert the needle in the middle third of the extensor surface of the forearm (Fig. 25.11a,b).

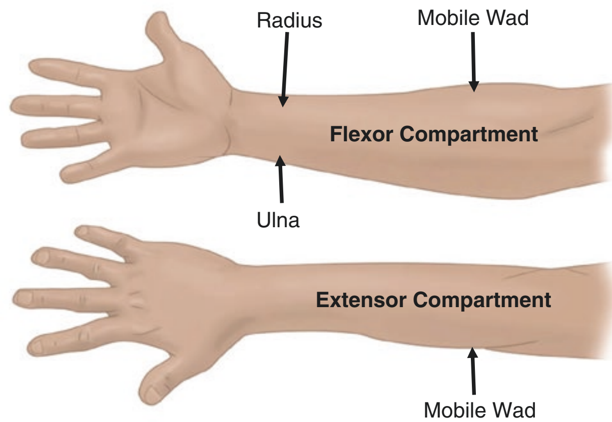


Fig. 25.9 Illustration of the forearm and its compartments. The forearm consists of three compartments flexor (volar), extensor (dorsal), and mobile wad (lateral)

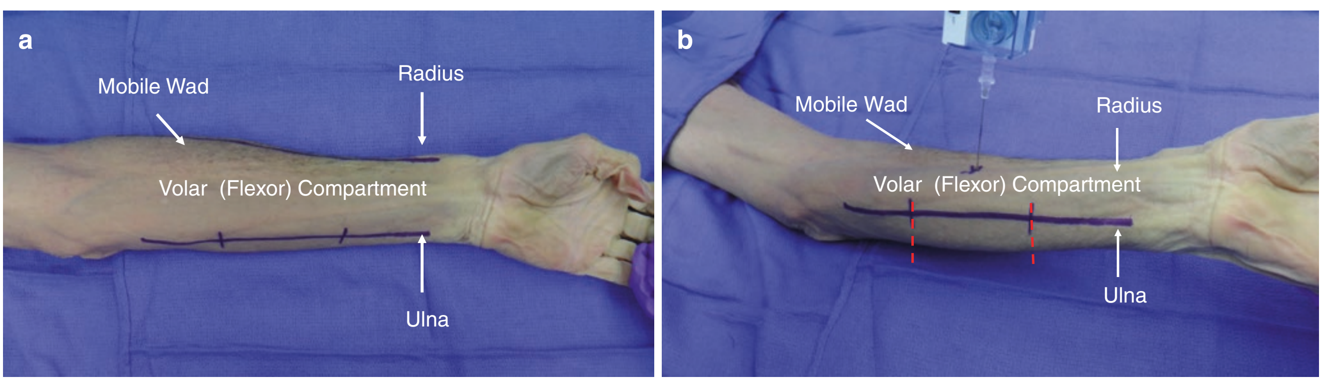


Fig. 25.10 (**a**, **b**) Measurement of pressures in the anterior compartment in the forearm: Insert the needle perpendicular to the skin in the middle third (between dotted red lines) of the flexor surface of the forearm. Avoid excessive flexion or extension of the wrist.

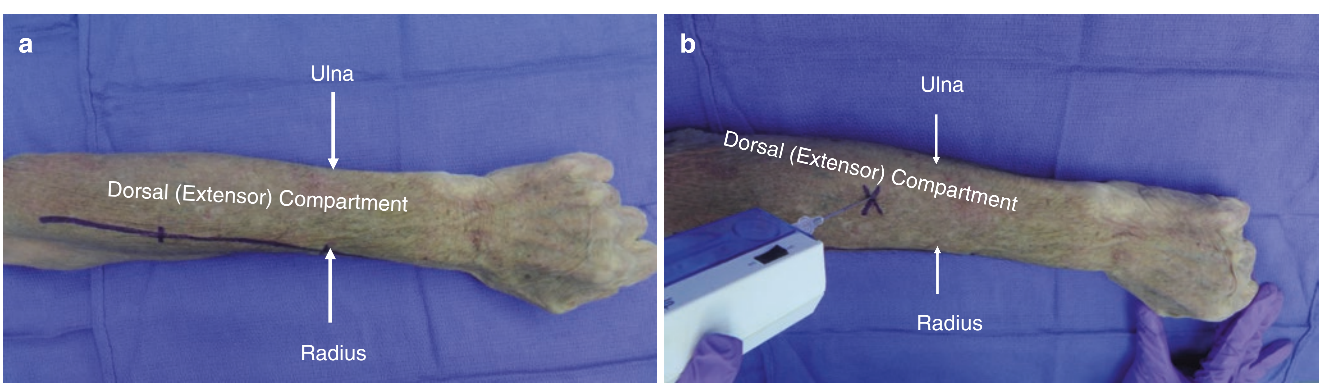


Fig. 25.11 (**a**, **b**) Measurement of the dorsal (extensor) compartment pressure: Insert the needle perpendicular to the skin in the middle third of the extensor surface of the forearm.

25.10 Buttock

- The buttock has three muscle compartments: the gluteus maximus compartment, the gluteus medius/minimus which is underneath the gluteus maximus, and the fascia lata compartment.
- Compartment pressures are best measured with the patient in prone or lateral positions (Fig. 25.12a).
- Insert the needle into the gluteus maximus, in the lateral upper quadrant to avoid injury to the sciatic nerve. For measurement of the pressure in the gluteus medius muscle compartment, push the needle deeper. This may require advancement of several centimeters in obese or muscular patients (Fig. 25.12b).

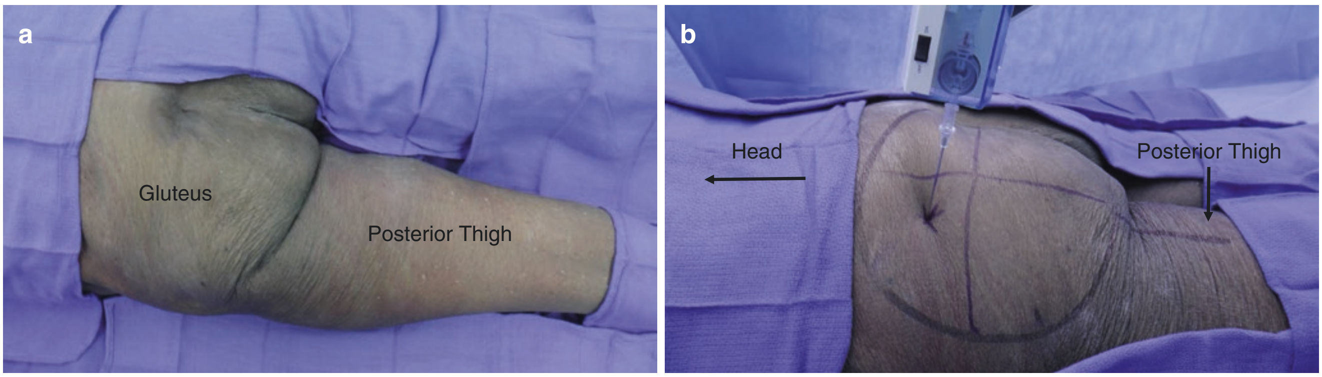


Fig. 25.12 (**a**, **b**) Measurement of pressures in the buttock muscle compartments: Place the patient in prone or lateral decubitus position. Insert the needle into the gluteus maximus and in the lateral upper quadrant to avoid injury to the sciatic nerve, which runs deep and in the middle of the buttock. For measurement of the pressure in the gluteus medius muscle compartment, push the needle deeper. This may require advancement of several centimeters in obese or muscular patients.

25.11 Lower Extremity

25.11.1 Thigh

- The thigh has three compartments: anterior, posterior, and medial. The medial muscle compartment contains the femoral vessels and the femoral nerve and is rarely affected by compartment syndrome. There is no need for routine decompression fasciotomy (Fig. 25.13).
- For anterior compartment pressures, insert the needle perpendicular to the skin, in the middle third of the anterior thigh. Avoid the medial aspect of the thigh, particularly the distribution of the superficial femoral artery which runs from the ligament to the medial epicondyle of the distal femur (Fig. 25.14a,b).
- For posterior compartment pressure, insert the needle in the middle third of the posterior thigh (Fig. 25.15a,b).

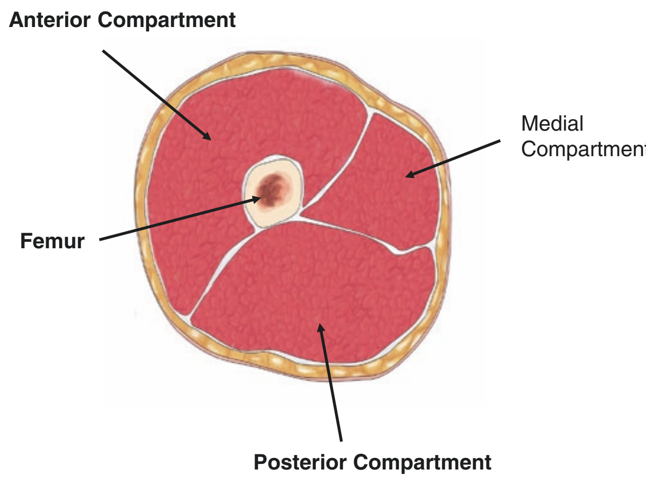


Fig. 25.13 Cross-sectional view of the right thigh compartments. The thigh consists of three muscle compartments: anterior, posterior, and medial. The right thigh is demonstrated here

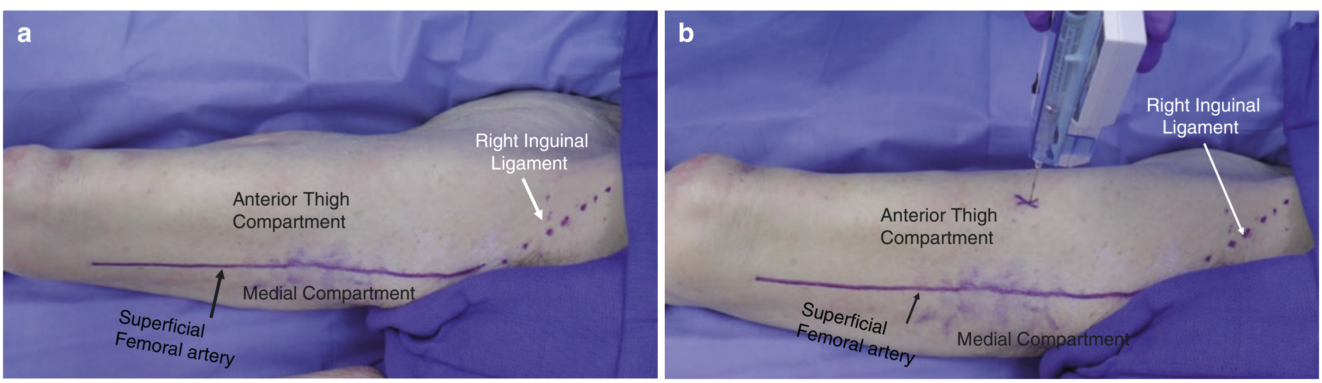


Fig. 25.14 (**a**, **b**) Measurement of the anterior thigh compartment pressure: Insert the needle perpendicular to the skin, in the middle third of the anterior thigh. Avoid the medial aspect of the thigh, particularly the distribution of the superficial femoral artery (blue line).

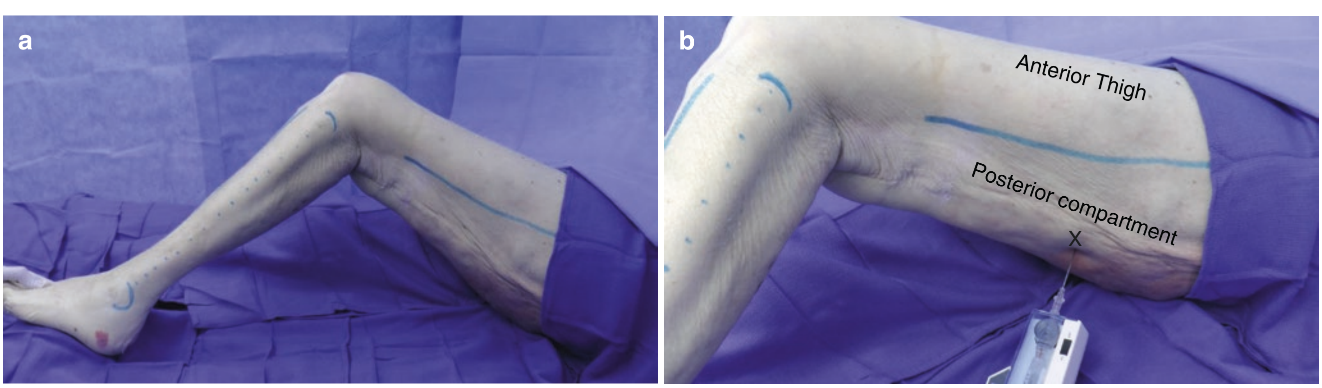


Fig. 25.15 (**a**, **b**) Left posterior thigh compartment pressure measurement: Flex the thigh at the hip in order to improve access to the posterior thigh. Insert the needle perpendicular to the skin, in the middle third of the posterior thigh.

25.12 Lower Leg

- The lower leg has four compartments: anterior, lateral, superficial posterior, and deep posterior (Fig. 25.16).
- The lower leg is divided in three thirds. At the junction of the proximal and middle thirds, draw a transverse line. This line is a good external landmark for the insertion of the needle for access to all four compartments (Fig. 25.17a–c).
- For measurement of the anterior compartment pressure, the needle is inserted perpendicular to the skin to a depth of 2–3 cm about 1–2 cm lateral to the anterior border of the tibia, at the junction of the upper and middle thirds of the leg. Proper needle placement can be confirmed by digital compression of the anterior compartment or dorsal flexion or plantar flexion during pressure measurements. These maneuvers result in a major increase of the pressure reading (Fig. 25.18).
- For measurement of the lateral compartment pressure, the entry point is about 1 cm in front of a line joining the head of the fibula and the lateral malleolus (this line corresponds to the fibula) and the junction of the upper and middle thirds of the leg. The needle is inserted perpendicular to the skin to a depth of 2–3 cm. Proper needle placement can be confirmed by an increase of the pressure with digital compression of the lateral compartment or inversion of the foot and ankle (Fig. 25.19).
- For measurement of the superficial posterior compartment pressure, the needle is inserted perpendicular to the skin to a depth of 2–3 cm, at a vertical line in the middle of the calf, and at the junction of the upper and middle thirds of the leg. Proper needle placement can be confirmed by an increase of the pressure with digital compression superficial posterior compartment or dorsiflexion of the foot (Fig. 25.20).
- For measurement of the deep posterior compartment pressure, insert the needle perpendicular to the skin, to a depth of 2–3 cm, just posterior to the medial border of the tibia, and at the junction of the upper and middle thirds of the leg. Proper needle placement can be confirmed by an increase of the pressure with toe extension or ankle eversion (Fig. 25.21).

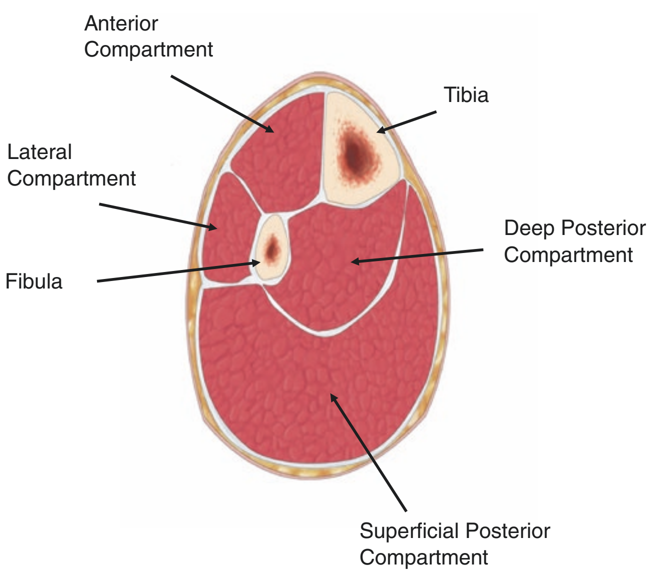


Fig. 25.16 Cross-sectional view of the right lower extremity. It includes four muscle compartments: anterior, lateral, superficial, and deep posterior. The right lower extremity is shown here

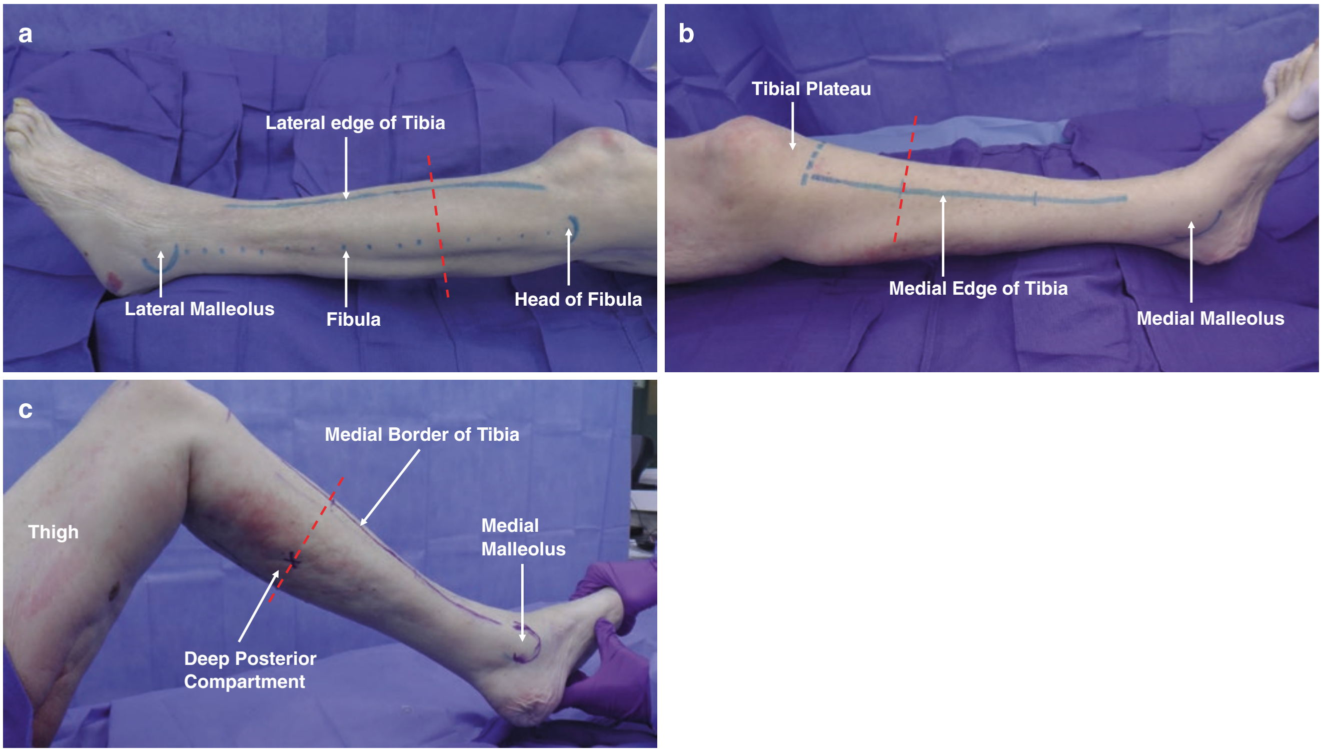


Fig. 25.17 (**a**) Left lower leg compartments: Important landmarks include the lateral edge of the tibia, tibial plateau, head of the fibula, and lateral malleolus. The blue dotted line corresponds to the length of the fibula. At the junction of the proximal and middle thirds (red line), draw a transverse line. This line is a good external landmark for the level of the insertion of the needle for access to all four compartments. (**b**) Left lower extremity compartments; the posterior compartments are most prominent in this position. The tibial plateau, the medial edge of the tibia, and the medial malleolus are important landmarks. (**c**) The left medial thigh and lower extremity are demonstrated here. The superficial posterior compartment can be better accessed in this position

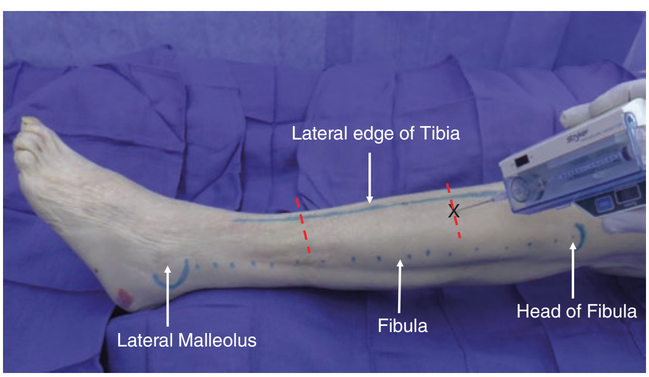


Fig. 25.18 Measurement of the anterior compartment pressure, left lower leg: The needle is inserted perpendicular to the skin to a depth of 2–3 cm about 1–2 cm lateral to the anterior border of the tibia, at the junction of the upper and middle thirds of the leg

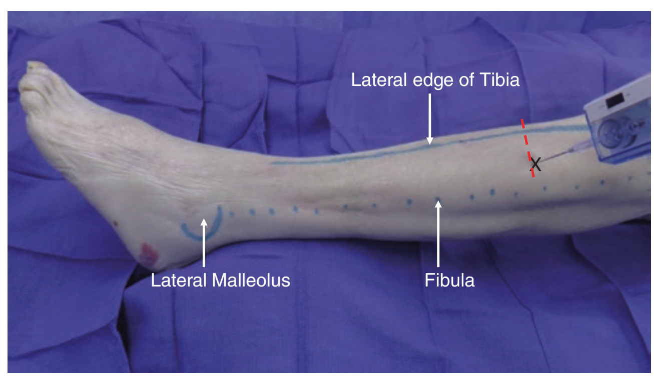


Fig. 25.19 Measurement of the lateral compartment pressure. Left lower leg: The entry point is about 1 cm in front of a line joining the head of the fibula and the lateral malleolus (this line corresponds to the fibula) and the junction of the upper and middle thirds of the leg (interrupted red line). The needle is inserted perpendicular to the skin to a depth of 2–3 cm

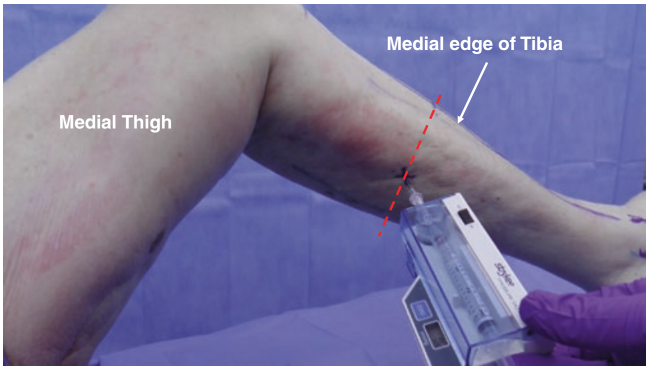


Fig. 25.20 Measurement of the superficial posterior compartment pressure, left lower leg: The needle is inserted perpendicular to the skin, to a depth of 2–3 cm, in the posterior leg, and at the junction of the upper and middle thirds of the leg (interrupted red line)

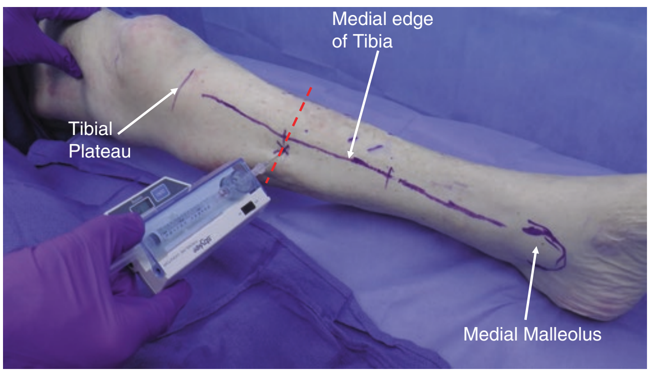


Fig. 25.21 Measurement of the deep posterior compartment pressure, left lower leg: The needle is inserted perpendicular to the skin to a depth of 2–3 cm, just posterior to the medial border of the tibia, at the junction of the upper and middle thirds of the leg (interrupted red line)

25.13 Tips and Pitfalls

- Delayed diagnosis is a common error! High index of suspicion, serial clinical examinations, compartment pressure measurements, and serial CPK levels remain the cornerstone of early diagnosis.
- Persistently elevated CPK levels in a critically ill patient should alert to the possibility of extremity compartment syndrome!
- Failure to measure the pressures in all compartments of the suspected area may miss the diagnosis of extremity compartment syndrome. The pressures may be normal in one compartment and abnormal in the adjacent one.
- Poor knowledge of the anatomy of the extremity muscle compartments is a common error!

Abdominal Pressure Measurement

26

Erin Palm and Aaron Strumwasser

26.1 General Principles

- Bladder pressure is a safe and minimally invasive method to measure intra-abdominal pressure (IAP) in the critically ill and injured.
- Normal intra-abdominal pressure is 0 mmHg. In severe obesity and pregnancy, chronically elevated IAP exists at baseline (10–15 mmHg) without adverse sequelae.
- For most critically ill patients, an IAP of 5–7 mmHg is considered normal.
- Intra-abdominal pressure of 10–15 mmHg results in decreased visceral organ perfusion.
- Intra-abdominal Hypertension (IAH) is defined as a sustained pathological elevation in intra-abdominal pressure (IAP) ≥12 mmHg in adults or >10 mmHg in children.
- Intra-abdominal hypertension severity is graded according to consensus guidelines.
  - Grade I (12–15 mmHg)
  - Grade II (16–20 mmHg)
  - Grade III (20–25 mmHg)
  - Grade IV (above 25 mmHg)
- Abdominal Compartment Syndrome (ACS) is defined as a sustained elevation in IAP >20 mmHg (>10 mmHg in children) that is associated with new organ dysfunction/failure.
- Abdominal perfusion pressure (APP): Mean Arterial Pressure (MAP)–IAP is a measure for perfusion of intra-abdominal organs. A target APP associated with appropriate perfusion is >60 mmHg.
- Abdominal Compartment Syndrome is classified as primary or secondary.
  - Primary ACS is due to a primary intra-abdominal cause such as abdominal trauma, pancreatitis, mesenteric venous obstruction, ascites, and retroperitoneal hemorrhage.
  - Secondary ACS or extra-abdominal syndrome refers to ACS that results from massive bowel edema from sepsis, capillary leak, massive fluid resuscitation, or burns.

26.2 Risk Factors

- Risk factors fall into four categories: diminished abdominal wall compliance, increased intraluminal contents, increased abdominal contents, and capillary leak/fluid resuscitation.
- Independent risk factors for primary ACS include the administration of more than 5 L of crystalloid infusion within 24 h, the transfusion of more than 10 packed red blood cell units in a 24 hour period, hypothermia (<33 °C), acidosis (base deficit < negative 14 mmol/L, pH < 7.2), and body mass index (>30). Excessive fluid resuscitation is the most common risk factor.
- Burn greater than 30% total body surface area (TBSA) is a risk factor for IAH, while greater than 50% TBSA and inhalation injury are risk factors for ACS.

26.3 Pathophysiology

- IAH affects multiple organ systems. The pathophysiology is the result of a mechanical component (high abdominal pressures) and a biochemical component (production of toxic lymph and toxins).
- Respiratory: Elevation in IAP results in an increase in thoracic pressure and diaphragmatic elevation causing a reduction in chest wall compliance, increased peak inspiratory pressure, and reduction of total lung capacity and functional residual volume which leads to hypoxia and hypercapnia.
- Cardiovascular: Elevated IAP directly compresses the inferior vena cava and portal vein, leading to an increase in systemic afterload, reduction in cardiac output, and hypotension.

E. Palm · A. Strumwasser (✉)
University of Southern California, Los Angeles County Medical Center, Los Angeles, CA, USA
e-mail: Aaron.strumwasser@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_26

- Abdominal viscera: Decreased hepatosplanchnic flow with impaired liver function and intestinal ischemia.
- Renal insufficiency occurs secondary to pre-renal causes (hypotension from reduced cardiac output) and intrinsic renal causes (vascular and parenchymal compression). Due to impaired renal blood flow a resultant decrease in urine output is observed.
- Impairment of lymphatic flow and an increase in intestinal edema. Extravasation of toxic lymph in the peritoneal cavity occurs.
- Increased intra-abdominal pressure may increase intracranial pressure which may aggravate an associated head trauma.

26.4 Clinical Findings

- Clinical manifestations of ACS include a distended and tense abdomen, elevated airway pressures with progressive hypoxia and hypercapnia, elevated heart rate with hypotension, and impaired renal function with oliguria that progresses to anuria without appropriate therapy.

26.5 Diagnosis

- A high index of suspicion is necessary to prevent IAH progressing to ACS.
- Bladder pressure should be monitored if ≥2 known risk factors for IAH/ACS are present in a critically ill or injured patient. After a baseline measurement, serial measurements should be performed.
- Protocolized bladder pressure monitoring in high-risk patients is essential.
- Bladder pressure is considered the gold standard for measuring the IAP.

26.6 Management

- Correct any hypovolemia but avoid excessive fluid resuscitation, especially with crystalloids.
- Sedation, analgesia, and neuromuscular blockade reduce IAP in appropriate cases.
- Decompress the gastrointestinal tract with nasogastric and rectal tubes.
- Drainage of any significant ascites, a common problem in extensive burns, may reduce the IAP.
- Removal excess fluid with diuretics or ultrafiltration.
- Perform escharotomies in abdominal burns.
- Abdominal decompression via decompressive laparotomy is the standard treatment for refractory IAH and ACS not responding to medical interventions.

26.7 Technique of Bladder Pressure Measurement

26.7.1 Supplies

- Two-way Foley catheter with a sampling port (alternatively, a three-way Foley catheter can be used)
- Set of IV tubing connected to a 500 mL bag of normal saline
- Two three-way stopcocks
- One 50 mL Luer Lock syringe
- Disposable pressure transducer
- Short segment of arterial line tubing

26.8 Patient Positioning

- The patient must be positioned supine.
- The transducer is set at zero at the midaxillary line level at the iliac crest.
- In patients on mechanical ventilation, the pressure should be obtained at end-expiration.

26.8.1 Technique

- Assemble all equipment at the bedside. Standard ICU equipment may be used (Fig. 26.1).
- Place a Foley catheter using sterile technique. Empty the bladder of urine before starting the procedure.
- Zero the patient at the iliac crest along the midaxillary line (Fig. 26.2).
- Connect the three-way stopcock to the Foley catheter sampling port. Clamp the tubing to the Foley bag (so no urine can drain). A 50 mL syringe should be placed on the remaining port of the three-way stopcock (Fig. 26.3).
- Connect the stopcock to the pressure tubing and CVP pressure transducer tubing, and flush the line with saline. See Fig. 26.4a–d.
- Instill 25 mL of normal saline into the bladder. In children 1 mL/Kg, maximum 25 mL (Fig. 26.5).
- Turn the stopcocks off to the syringe and IV tubing (Fig. 26.6).
- Wait for 30–60 s for detrusor relaxation following instillation of saline, and obtain bladder pressure at end-expiration (in mmHg) (Fig. 26.7).

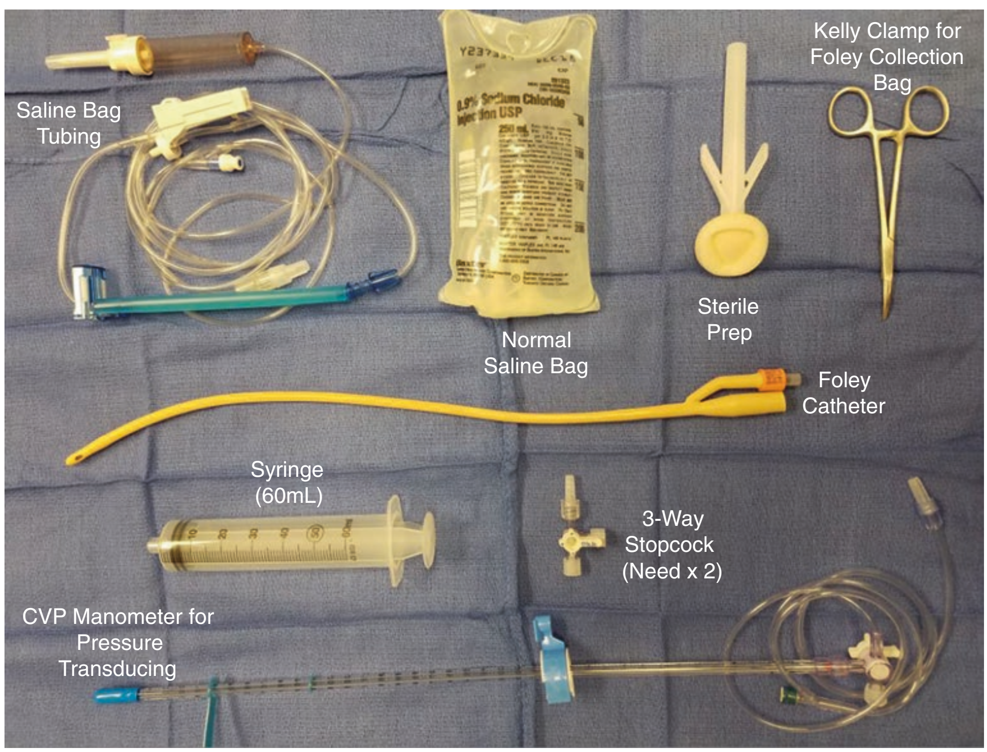


Fig. 26.1 Standard equipment for measuring abdominal pressure (University of Southern California SICU setup)

Fig. 26.2 Prepare the patient by placing them supine and zeroing at the midaxillary line (approximately the iliac crest)

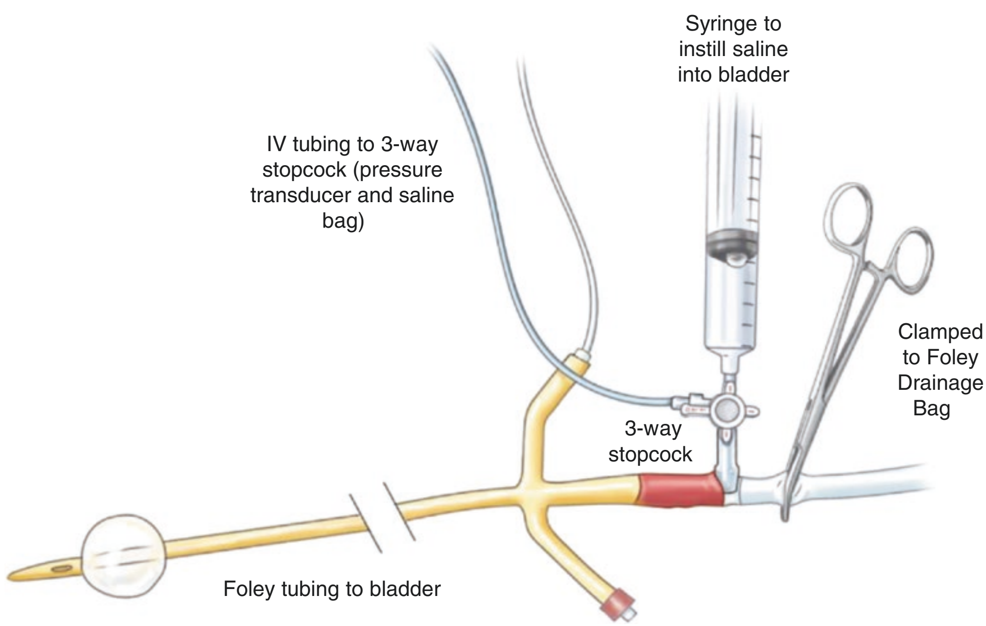


Fig. 26.3 Bladder pressure setup at Foley. Be sure to flush all tubing with saline as air bubbles will confound measurements. After flushing, clamp the urinary drainage port, and turn the stopcocks off (toward the patient)

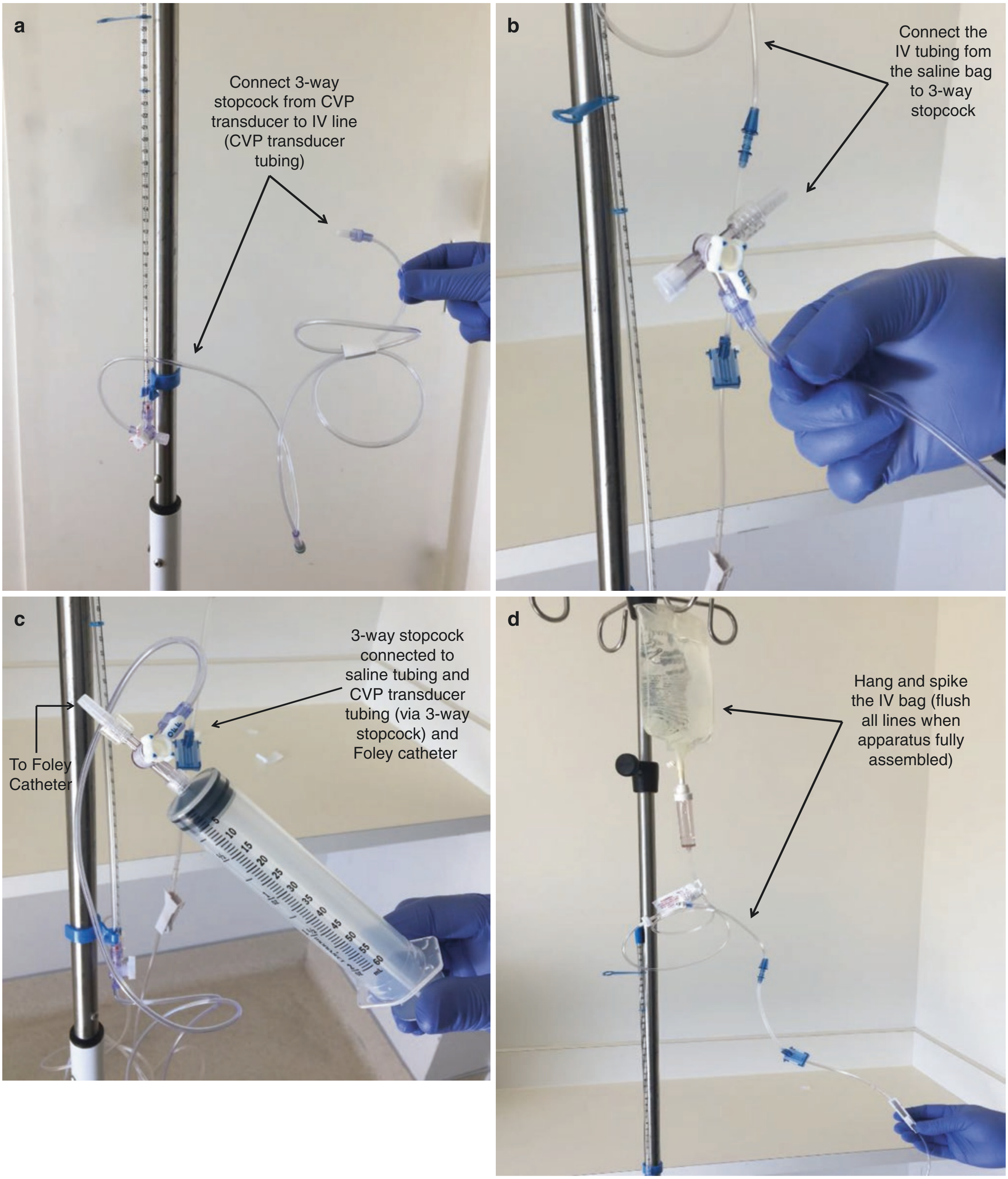


Fig. 26.4 (**a**) Apparatus for bladder pressure measurement shown. Connect three-way stopcock at the CVP transducer (connected to three-way stopcock coming from saline line). (**b**) Attach three-way stopcock at the distal end of the saline line (connected to CVP transducer and Foley three-way stopcock). (**c**) Connect the IV tubing from the saline line at the Foley (connected to Foley drainage catheter, 50 mL syringe, and clamped urinary collection bag). (**d**) Hang and spike the bag. Once the bag is spiked, flush all lines, and turn stopcocks off to prevent air entry into the system

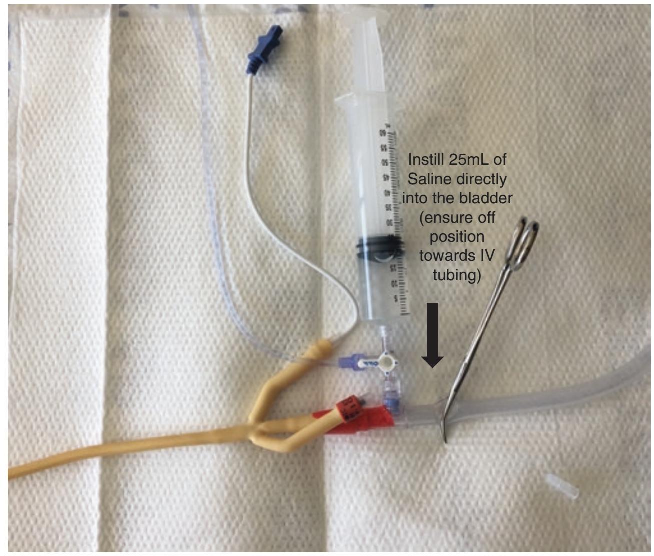


Fig. 26.5 Fill the (previously emptied) bladder with 25 mL of normal saline. In children, use approximately 1 mL/kg (max 25 mL)

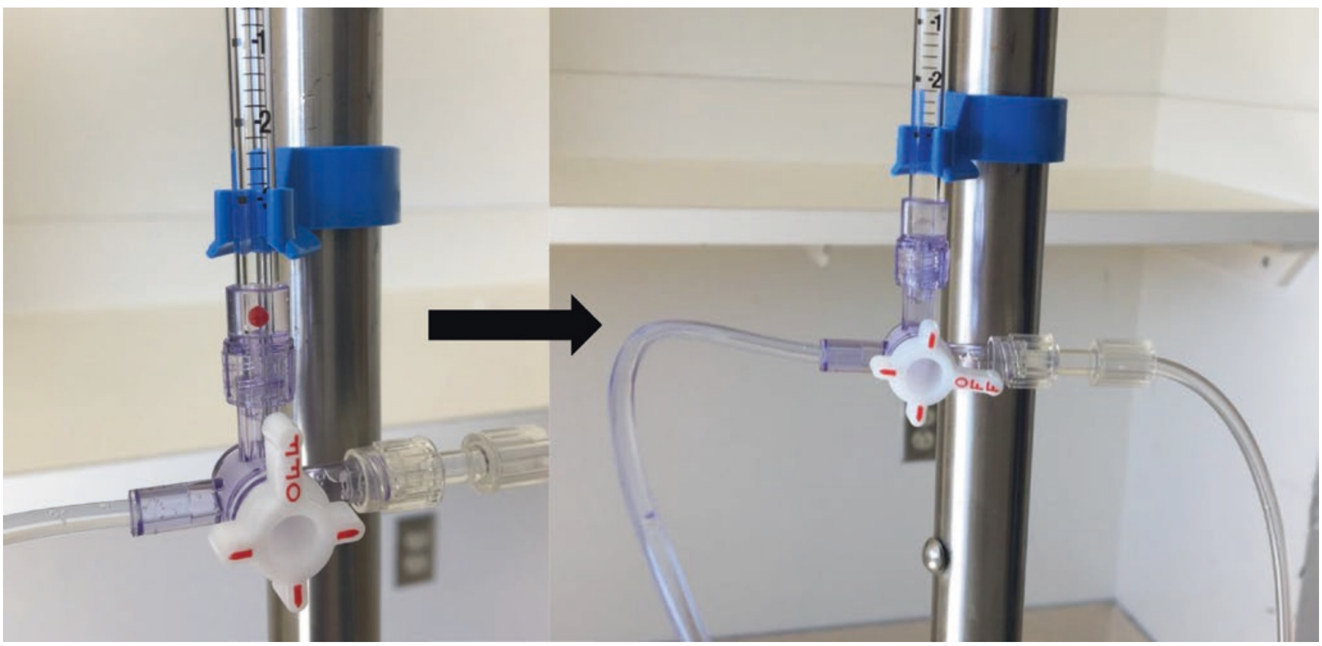


Fig. 26.6 Turn the stopcock to off position (to IV tubing), and measure intra-abdominal pressure

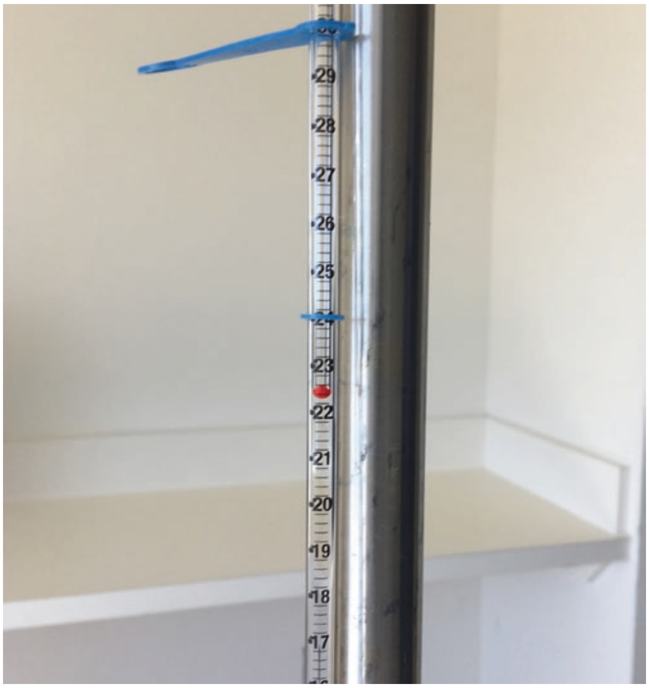


Fig. 26.7 Measurement of bladder pressure (CVP manometer in cm)

26.9 Tips and Pitfalls

- A high index of suspicion is necessary for early diagnosis, before IAH progresses to ACS. IAP should be measured if two or more risk factors for IAH/ACS in a critically ill or injured patient are present.
- The intravesicular instillation volume should be a maximum of 25 mL saline (in children 1 mL/Kg, maximum 25 mL) to avoid overdistention and falsely elevated IAP.
- Wait 30–60 s before pressure measurement for detrusor muscle relaxation, to avoid a falsely elevated pressure.
- The IAP should be measured at end-expiration with the patient supine and the transducer zeroed at the iliac crest at the midaxillary line.
- Bladder pressure may not be accurate in patients with abdominal packs, pelvic fractures, intraperitoneal adhesions, hematomas, neurogenic bladder, obesity, and pregnancy.
- The bladder pressure is expressed in mmHg if a transducer is used or in cm H_2O if a CVP set is used. 1 mmHg = 1.34 cm H_2O.

27 Bedside Laparotomy and Decompression of Abdominal Compartment Syndrome

Erin Palm and Daniel Grabo

27.1 General Principles

- Intra-abdominal hypertension (IAH) is defined as a sustained intra-abdominal pressure, as measured with bladder pressure, >12 mmHg in adults or >10 mmHg in children. Abdominal compartment syndrome (ACS) is defined as a sustained bladder pressure >20 mmHg in adults or >10 mmHg in children, combined with evidence of new organ dysfunction or failure, i.e., respiratory or renal failure.
- ACS may be primary (due intra-abdominal conditions such as trauma, major surgery, peritonitis) or secondary (due to extra-abdominal conditions, such as massive fluid administration in burns or trauma).
- IAH and ACS should be suspected in the presence of a distended abdomen and are often associated with increasing peak inspiratory pressure in mechanically ventilated patients, progressive hypoxia and hypercapnia, tachycardia, hypotension, and oliguria.
- The diagnosis of ACS is confirmed by elevated intra-abdominal pressure (reference pressures above) as measured by bladder pressures in combination with any of the above clinical findings.
- In patients with borderline ACS, the intra-abdominal pressure can be reduced by restricting intravenous fluids, pain control, pharmacological paralysis, decompression of the gastrointestinal tract by means of a gastric or rectal tubes, and percutaneous drainage of large ascites (often effective in burn patients).
- In patients with severe ACS not responding to conventional measures, a decompressive laparotomy should be considered without any delay.
- Decompressive laparotomy is usually performed in the operating room. However, in some cases with severe ACS, bedside laparotomy in the ICU should be performed. Indications for bedside laparotomy include:
  - Patient instability for transport.
  - Operating room unavailable.
  - Suboptimal, austere environments, where a fully equipped OR may not be available in a timely manner.
- During decompressive laparotomy, the patient may experience severe hemodynamic decompensation or cardiac arrest, due to pooling of significant blood volume in the visceral vascular bed and reperfusion effects.
- Following decompressive laparotomy, the abdomen should be managed with temporary abdominal wall closure.
- Surgical definitive abdominal wall closure should be performed at the earliest possible time to avoid complications associated with having an open abdomen, such as entero-atmospheric fistulas and fascial retraction.

E. Palm
University of Southern California, Los Angeles County Medical Center, Los Angeles, CA, USA

D. Grabo (✉)
West Virginia University, Morgantown, WV, USA
e-mail: daniel.grabo@hsc.wvu.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_27

27.2 Preparation

- Gather supplies including a laparotomy tray with sterile instruments typically used in the operating room, including a scalpel, scissors, forceps, sponges, surgical towels, large transparent adhesive dressing, clamps, and suture for obtaining hemostasis. Richardson and Balfour retractors may be useful for exploring the abdomen if hemorrhage or other intra-abdominal pathologies are suspected. If available, monopolar electrocautery with proper grounding can be useful. Set up a suction device with sterile suction tubing.
- Position the patient supine. The arms can be left down at the patient's sides in the ICU environment.
- Sterile operative technique should be observed. Sterile prep solution (chlorhexidine or betadine), full abdominal drapes, and sterile precautions for all operators should be available; see Fig. 27.1.

Fig. 27.1 Prepping for ICU bedside laparotomy. Bedside laparotomy in the ICU is set up in a similar way to the operating room. Sterile draping as well as sterile attire is used. Basic instrumentation, equipment, and monitoring are also necessary

27.3 Laparotomy Technique

- The laparotomy should be performed by a trained general surgeon.
- Sterilely prep and drape the abdomen, exposing the patient from the level of the nipples to the groin.
- Make a generous incision in the skin of the abdominal midline extending from the xiphoid to the pubis. The incision can be made sharply with a scalpel or with cautery. Incise through the subcutaneous tissue along the length of the incision to expose the fascia in the abdominal midline. Then incise the fascia in the linea alba above the umbilicus. This will expose pre-peritoneal fat. Abdominal entry is typically easier in the upper midline, rather than below the umbilicus. See Fig. 27.2.
- Extend the incisions from the xiphoid to pubis, placing a hand under the peritoneum to protect the bowel underneath from inadvertent injury. The incision should be generous in order to completely decompress the abdominal compartment. See Figs. 27.3 and 27.4.
- At times, intra-abdominal pathology will be encountered that will require additional operative management, for example, hemorrhage or ischemic bowel. Ideally this pathology is addressed in a fully equipped operating room.

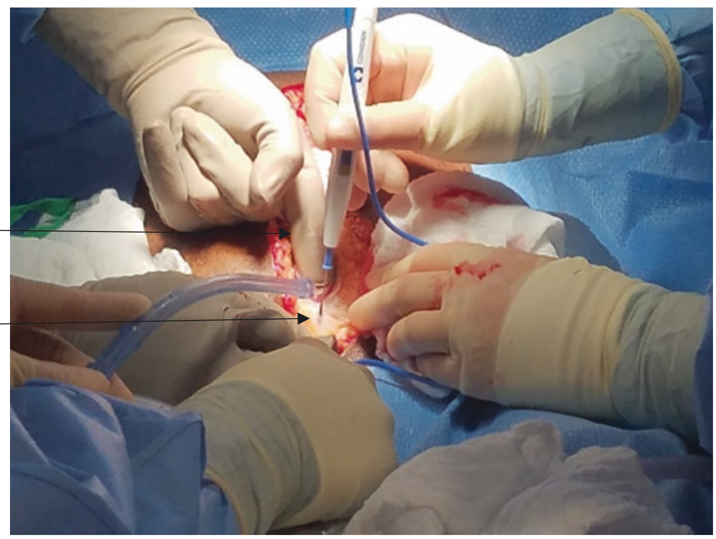


Fig. 27.2 Incision and abdominal entry for bedside laparotomy. A generous incision is made in the midline of the abdomen from the xiphoid to the pubic symphysis. This can be done sharply or with cautery. The linea alba is divided and the abdomen is entered. It is best to enter the abdomen above the umbilicus

Fig. 27.3 Abdominal decompression. Once the fascia, pre-peritoneal fat, and peritoneum are divided, the abdominal viscera are then released, allowing decompression and relief of the abdominal compartment syndrome

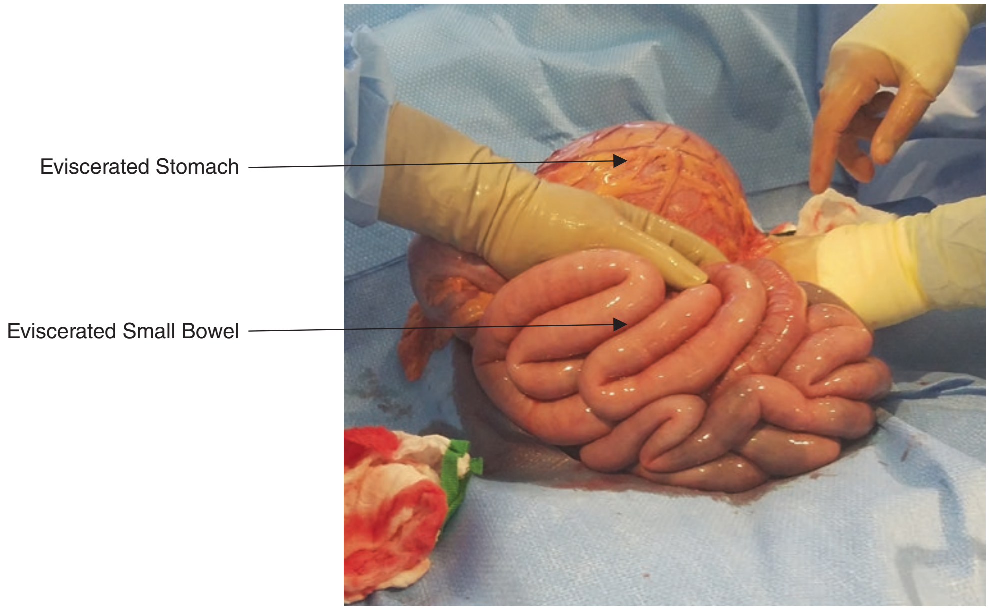


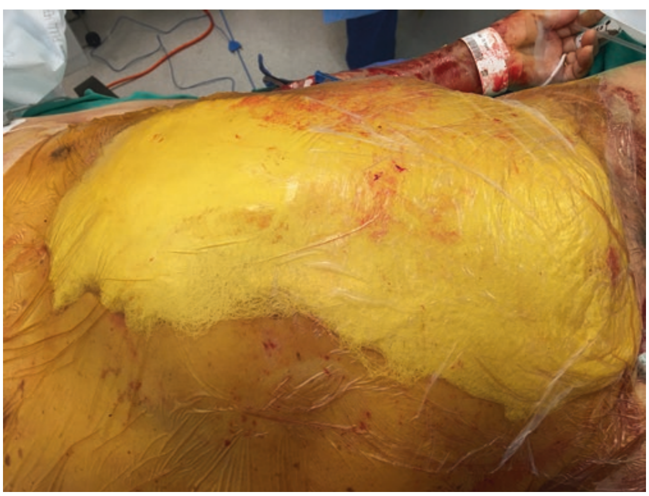
Fig. 27.4 Decompression of the stomach and small bowel. There is often significant edema and dilation of hollow viscus organs resulting in evisceration

27.4 Temporary Abdominal Wall Closure

- Following decompressive laparotomy, the abdominal wall should be temporarily closed to avoid evisceration. If the etiology of the ACS is due to an abdominal pathology (primary ACS), the operation should be transferred immediately to the operating room for definitive surgical management. In secondary ACS (non-specific massive bowel edema), there is no need for immediate completion in the operating room.
- Various materials and techniques can be used for temporary abdominal closure following decompressive laparotomy. They include simple techniques using immediately available materials and various commercially available negative pressure therapy (NPT) devices.
- For bedside decompressive laparotomies, temporary closure can be done by covering the exposed bowel with wet gauze or sterile towels which are kept in place with a large plastic adhesive dressing (Fig. 27.5).
- Other techniques for temporary abdominal closure are described in Chap. 10.

27.5 Tips and Pitfalls

- Severe ACS is a surgical emergency. Consider bedside decompressive laparotomy if the patient is in extremis or if there is no operating room immediately available.
- Selected patients with secondary IAH and ACS can be managed with conservative methods, such as restricting intravenous fluids, pain control, pharmacological paralysis, decompression of the gastrointestinal tract, and percutaneous drainage of large ascites.
- Delayed diagnosis of IAH and ACS is common.
- Following decompressive laparotomy for ACS, there is a significant hemodynamic, respiratory, and urine output improvement. If the peak inspiratory pressures do not improve, consider alternative diagnoses.



Sterile gauze covered with sterile adhesive drape

Fig. 27.5 Temporary abdominal closure. It is best not to perform surgical fascial or definitive closure after relief of ACS or after performing bedside laparotomy. Temporary closure is best achieved by using readily available commercial devices or materials (gauze, sterile towels, plastic adhesive drapes)

Bedside Escharotomies for Burns

28

Christine Yin, Demetrios Demetriades,
and Warren Garner

28.1 General Principles

- Deep second- or third-degree circumferential burns of the neck, chest, abdomen, or extremities can cause many serious local and systemic problems.
  - Circumferential burns of the neck can cause airway obstruction.
  - Circumferential burns of the chest can decrease chest wall compliance, which can cause respiratory compromise, increased peak inspiratory pressures, hypoxia and hypercapnia, and decreased venous return to the heart, which aggravates hypotension and tachycardia.
  - Circumferential burns of the abdomen can cause intra-abdominal hypertension and abdominal compartment syndrome.
  - Circumferential burns of the extremities can cause compartment syndrome and result in sequelae ranging from acute kidney injury to permanent neuromuscular damage and limb loss.
- In severe burns requiring massive amounts of fluid resuscitation, abdominal or extremity compartment syndromes may develop independent of circumferential burns. These patients may need decompressive laparotomy or extremity fasciotomy in addition to the escharotomy. These high-risk patients should have bladder and extremity compartment pressures monitored in conjunction with clinical monitoring of urine output, abdominal exams, compartment checks, and vascular exams.

28.2 Indications

- A prophylactic escharotomy should be done routinely in all patients with completely circumferential deep second- or third-degree burns. In burns which are not completely circumferential, escharotomies should be considered on the basis of clinical findings and measurements of bladder or extremity pressures.
- Ideally, escharotomies should be performed in the operating room. However, in unstable patients or if the operating room is not immediately available, the procedure can be performed at bedside in the intensive care unit.

28.3 Equipment

- Sterile drapes, gown, gloves, mask, cap, and eye protection.
- Povidone-iodine solution, gauze, and dressing materials.
- Electrocautery, with grounding pad on unburned skin if possible.
- Wall suction.
- Sedation medications or IV bolus of existing medications if patient is already sedated and intubated.

C. Yin · W. Garner
Department of Surgery, University of Southern California,
Los Angeles, CA, USA
e-mail: wgarner@med.usc.edu

D. Demetriades (✉)
University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_28

28.4 Technique

- Sedate patient or increase sedation and pain control before manipulation.
- Betadine prep and drape the affected areas.
- Incisions should be planned so that maximum release can be achieved with the fewest number of incisions.
- The burn should be incised fully through the eschar and dermis, down to the subcutaneous tissue. If there is a suspicion of underlying muscle compartment syndrome based on appearance or increased compartment pressure despite escharotomy, a standard extremity fasciotomy may be necessary. In patients with suspected abdominal compartment syndrome, the bladder pressures should be measured, and in the appropriate cases, a decompressive laparotomy should be performed.
  - Chest and abdomen (Fig. 28.1)
    The incisions are marked and should at the very least include midaxillary lines, ventral midline, and any necessary transverse lines across the full-thickness areas (2–4 depending on patient size and extent of burn).
    The burn is incised fully through the eschar and dermis revealing subcutaneous fat. The amount of release between the two skin edges should be about 1 in.. Upon adequate release, there should be an immediate hemodynamic response and/or decrease in bladder pressure.
  - Extremities (Figs. 28.2, 28.3)
    The incisions are marked and should span the medial and lateral sides of the entire length of the extremity or the entire length of burn.
    The burn is incised fully through the eschar and dermis, again revealing about 1 in. of separation between skin edges.
    The same principles of incision in the upper extremity can be applied to the lower extremity. Adequate release can be assessed with softening of the compartments and return of palpable pulses or dopplerable signals.
  - Hand: dorsal hand incisions and medial and lateral finger incisions
    The amount of release between skin edges for the hand may be significantly less than 1 in. as the surface area is much smaller. Adequate release in the hand can be assessed with palpation of compartments and dopplerable signals in the radial artery, ulnar artery, and superficial palmar arch (Fig. 28.4).
- Hemostasis should be achieved with coagulation setting quickly and efficiently.
- Incisions and burns should be immediately dressed in antibacterial dressing to avoid further hypothermia and infection.

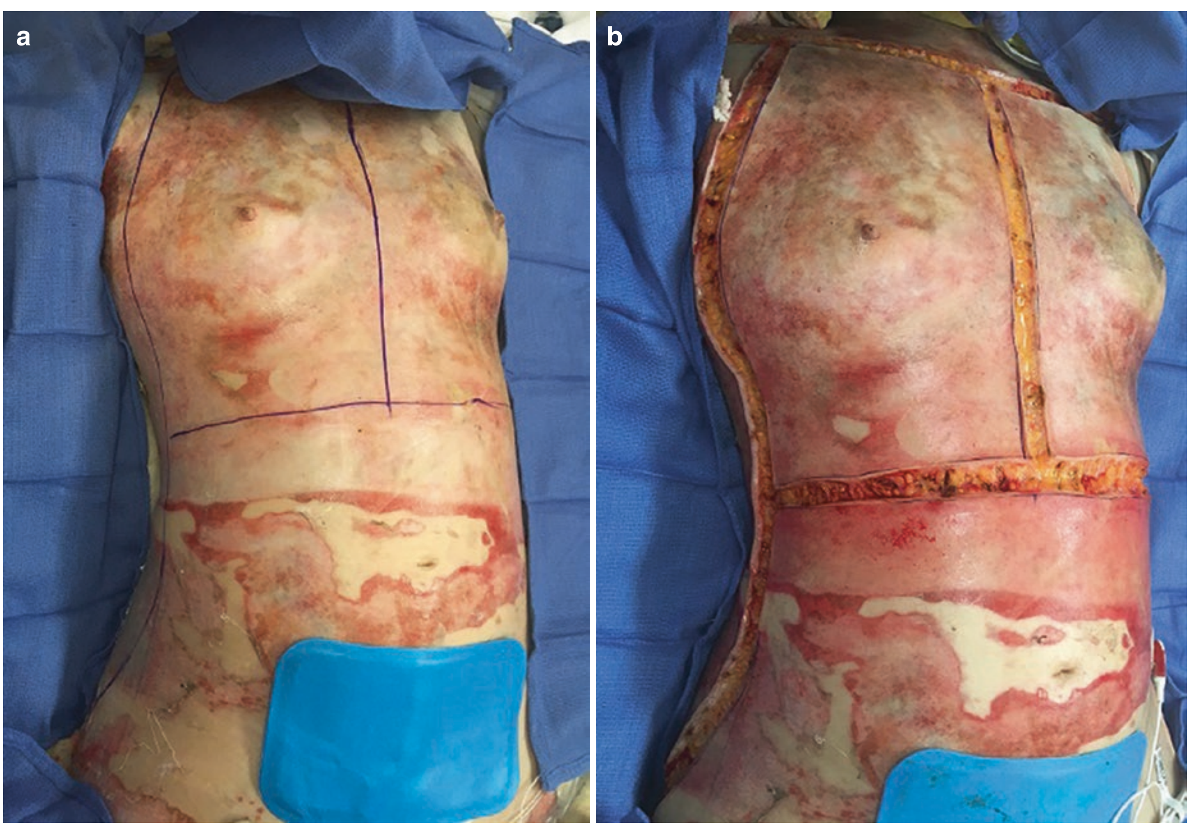


Fig. 28.1 (**a**, **b**) Escharotomy of the chest: The incisions should include midaxillary lines, ventral midline, and any necessary transverse lines across the full-thickness areas. The burn is incised fully through the eschar and dermis, down to the subcutaneous fat

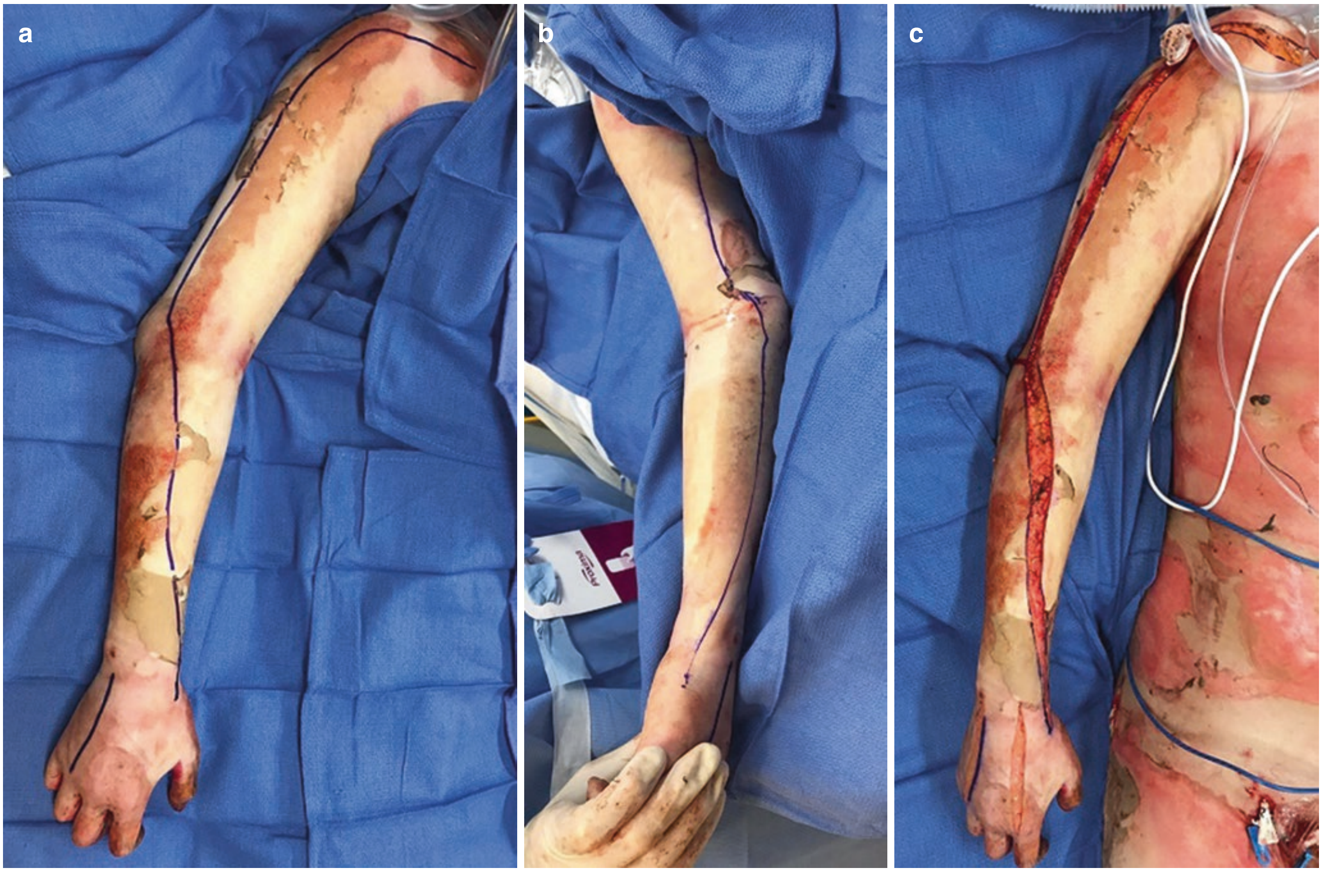


Fig. 28.2 (**a**–**c**) Escharotomy of the upper extremity: The incisions should span the medial and lateral sides of the entire length of burn. The burn is incised through the eschar and dermis, down to the subcutaneous fat

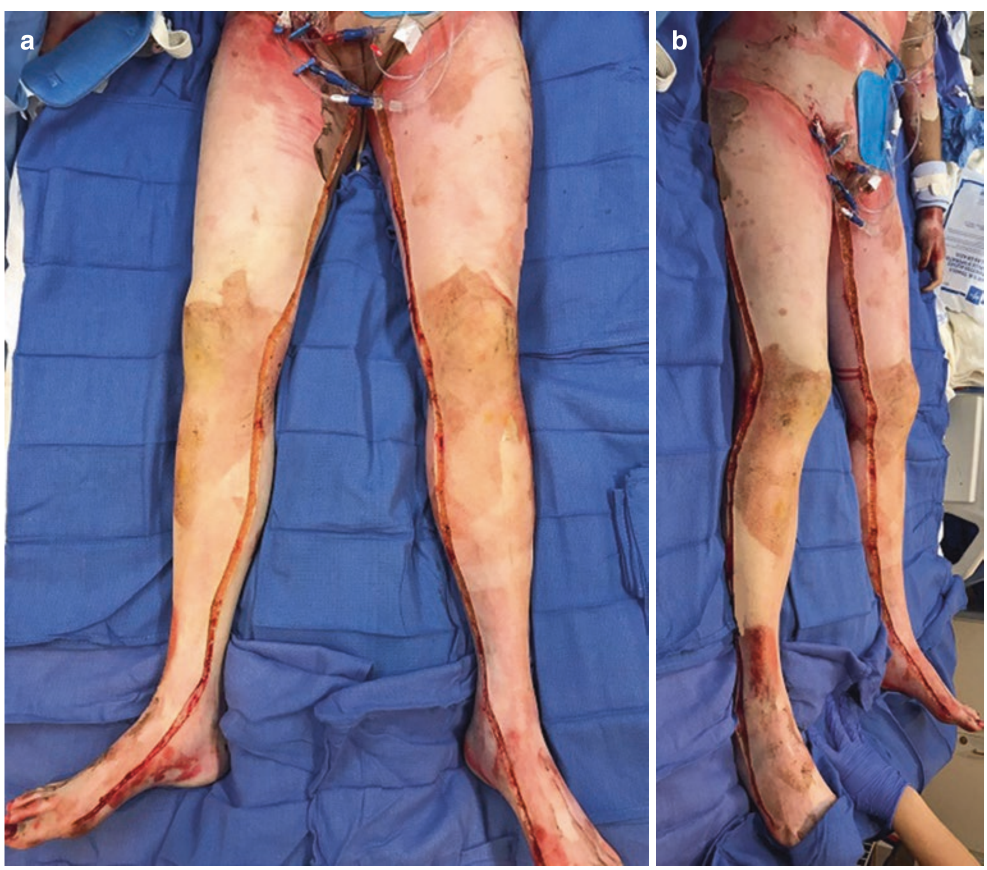


Fig. 28.3 (**a**, **b**) Escharotomy of the lower extremity: Medial and lateral incisions decompressing the entire length of burn

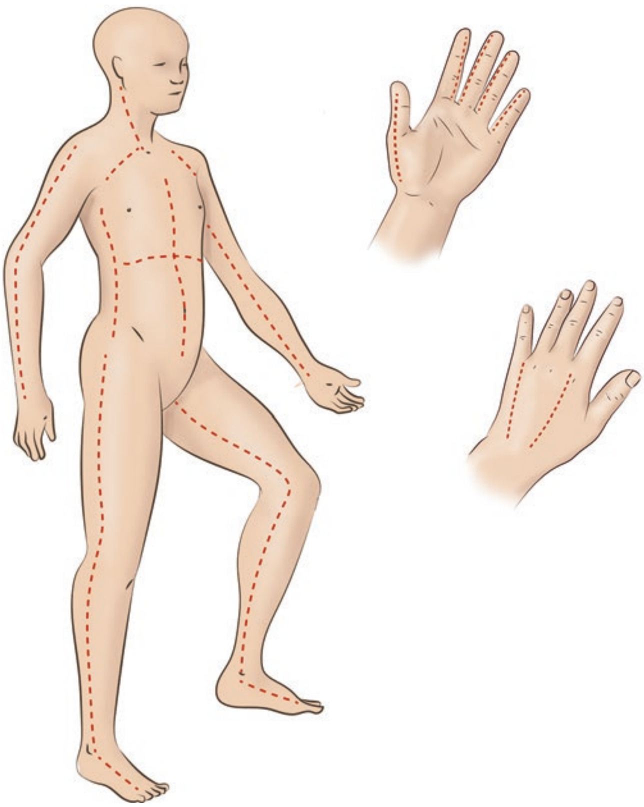


Fig. 28.4 Incisions for common escharotomy incisions in the trunk and extremities

28.5 Tips and Pitfalls

- It may be helpful to mark before incising as it is difficult to assess rotation and landmarks in patients with edema.
- Avoid injury to critical structures while making incisions.
  - Upper extremity: ulnar nerve in the median cubital tunnel, radial artery and superficial radial nerve in the radial aspect of the wrist, and major superficial veins if patient only has peripheral access.
  - Lower extremity: peroneal nerve in the lateral aspect of the knee and saphenous veins along the medial aspect of the leg.
  - Hand: keep dorsal to finger creases to avoid digital nerves and arteries.
- Extensive burns and hypothermia are often associated with coagulopathy. Escharotomy can result in excessive blood loss. Correct coagulopathy with warming measures and blood products, and minimize blood loss with good local hemostasis.
- In severe burns requiring massive amounts of fluid resuscitation, abdominal or extremity compartment syndromes may develop independent of the circumferential burns. It is essential to monitor the bladder and extremity compartment pressures and perform a decompressive laparotomy or extremity fasciotomy in addition to the escharotomy.

Negative Pressure Wound Therapy for Soft Tissue Infections

29

Elizabeth R. Benjamin and Demetrios Demetriades

29.1 General Principles

- The principles in the management of severe soft tissue infections include:
  - Debridement of dead and ischemic tissues
  - Systemic antibiotics for invasive infections
  - Local wound care
- Negative pressure wound therapy (NPWT) may benefit patients with severe soft tissue infections, such as:
  - Necrotizing soft tissue infections
  - Surgically drained septic arthritis
  - Surgically drained infected orthopedic implants
  - Infected wounds with exposed bone
  - Surgically treated osteomyelitis
  - Diabetic foot infections
- Adequate surgical debridement is an absolute requirement before NPWT.
- NPWT provides a closed and moist environment, increases perfusion, decreases edema, removes infected fluid, promotes granulation, and reduces wound volume.
- NPWT can be enhanced by using a built-in automated irrigation system (V.A.C. VeraFlo System). This concept allows slow introduction of a predetermined volume of irrigation fluid, soaking of the wound for a defined period of time, removal of the irrigation fluid, and maintenance of negative pressure therapy for a defined interval before the cycle repeats.
- NPWT with instillation is associated with:
  - Enhanced granulation tissue production
  - Decreased bacterial load
  - Fewer surgical debridements
  - Shorter time to wound closure
  - Fewer hospital days
- Irrigation fluids that can be used with VAC irrigation system include normal saline, Dakin's solution, polyhexanide, acetic acid solution, and antibiotic solution.

29.2 Contraindications for NPWT

- Negative pressure therapy should never be applied in the presence of incomplete hemostasis.
- Foam should never be placed directly over exposed blood vessels or intra-abdominal organs.
- NPWT should not be considered in the setting of residual malignancy, untreated osteomyelitis, or persistent necrotic tissues.

E. R. Benjamin · D. Demetriades (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_29

29.3 Equipment

- Commercial NPWT automated irrigation systems include the pump and disposables (various sizes, types, and shapes of foam, irrigation and suction pads with tubing, canisters, and adhesive drapes; Fig. 29.1).
- Several commercially available foam options exist, and the dressing may be customized based on the wound characteristics.
  - GranuFoam: a standard black polyurethane foam.
  - GranuFoam Silver: a silver-impregnated foam.
  - WhiteFoam: a polyvinyl alcohol dressing with reduced tissue adherence, appropriate for use near vessels or viscera, covered with a GranuFoam layer.
  - Cleanse Choice: base layer designed to mechanically disrupt and debride wounds, designed to be placed as a contact layer covered with two additional layers of GranuFoam (Fig. 29.2).

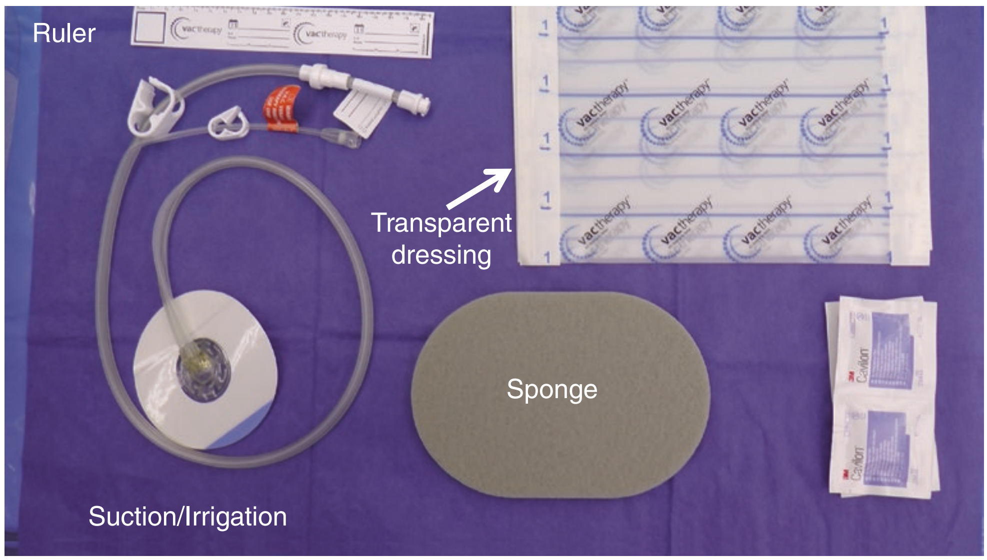


Fig. 29.1 Commercially available kit for negative pressure wound therapy with intermittent irrigation including suction/irrigation tubing, sponge, and transparent dressing

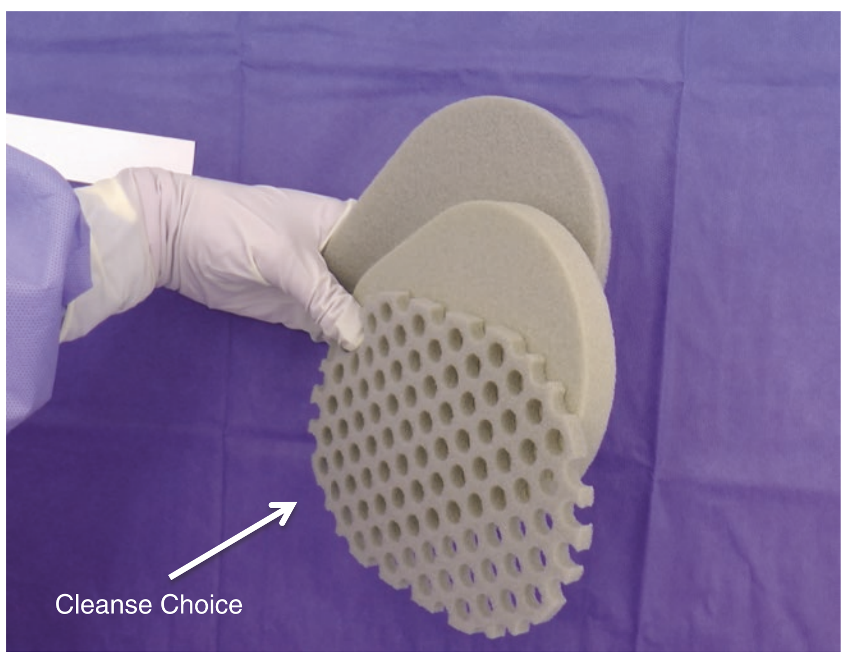


Fig. 29.2 Cleanse choice sponge option with perforated base layer and two additional granufoam layers

29.4 Preparation and Technique

- Devitalized tissue should be surgically excised and any abscess collection drained prior to application of NPWT.
- Cover vessels, nerves, or viscera with petroleum-impregnated gauze (Vaseline gauze) or white foam.
- Cut the foam to size and place it over the wound. In deep wounds a second layer of foam may be used (Fig. 29.3).
- Cover foam with a transparent adhesive drape.
- Cut a round hole in the adhesive drape, approximately 1 cm in diameter (Fig. 29.4).
- Apply the dual irrigation/suction pad (Fig. 29.5).
- Connect the irrigation channel to the irrigation tubing and container with the irrigation fluid.
- Connect the suction channel to the negative pressure collection canister. Check pump monitor for dressing leaks.
- For large wounds, a separated irrigation and suction pad system with a Y connector is available. When using the separated system, apply the suction arm in the dependent position (Fig. 29.6).
- Determine settings on the pump for volume and duration of irrigation fluid instillation and duration and level of negative pressure therapy (Fig. 29.7).
- The international consensus guidelines for NPWT with instillation recommend soak time 10–20 min and pressures 125–150 mmHg.
- The settings may be changed manually depending on the size and nature of the wound. Larger wounds need larger instill volumes. Empirically the instill volume can be estimated by the amount of fluid needed for the foam to become saturated (indicated by a darker color change; Fig. 29.8).

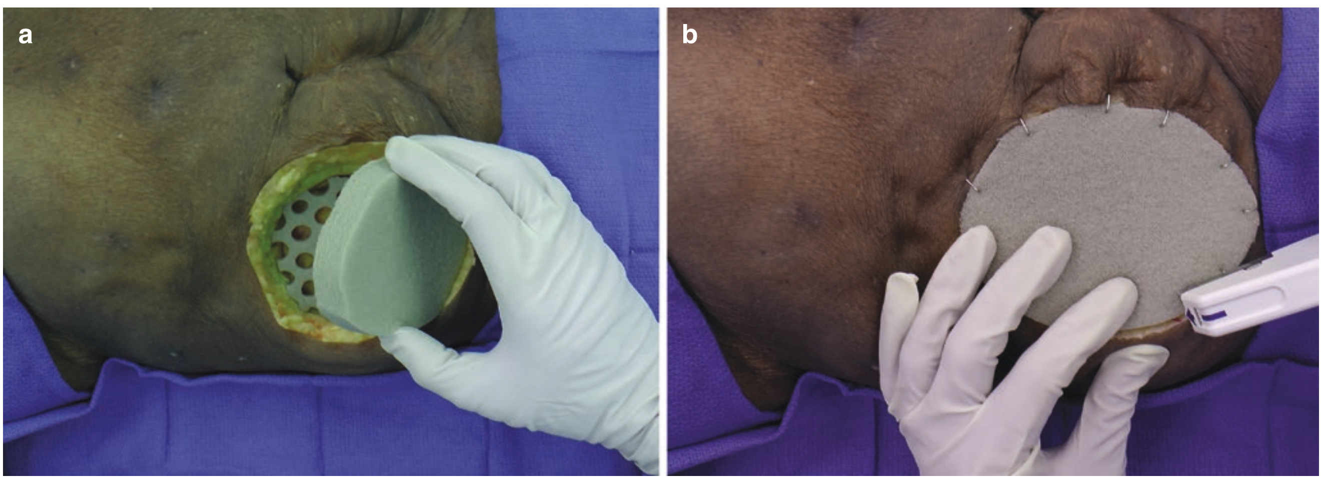


Fig. 29.3 Cut sponge to fit wound. If using the cleanse choice sponge, apply perforated sponge first and additional ganufoam layers on top (**a**). Sponge may be stapled to the skin edges (optional; **b**)

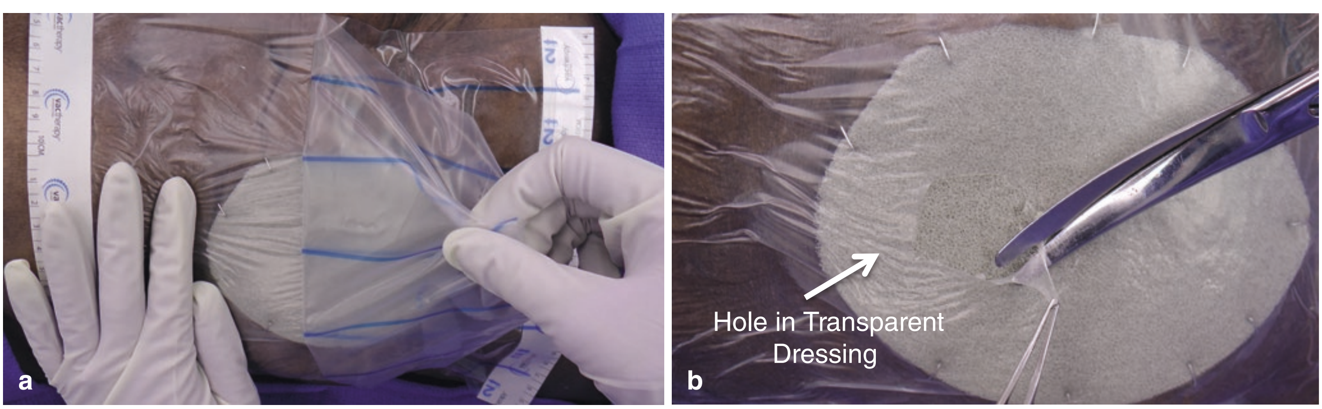


Fig. 29.4 Cover the sponge with a transparent dressing (**a**) and remove a quarter size piece, ideally in a dependent area of the wound (**b**)

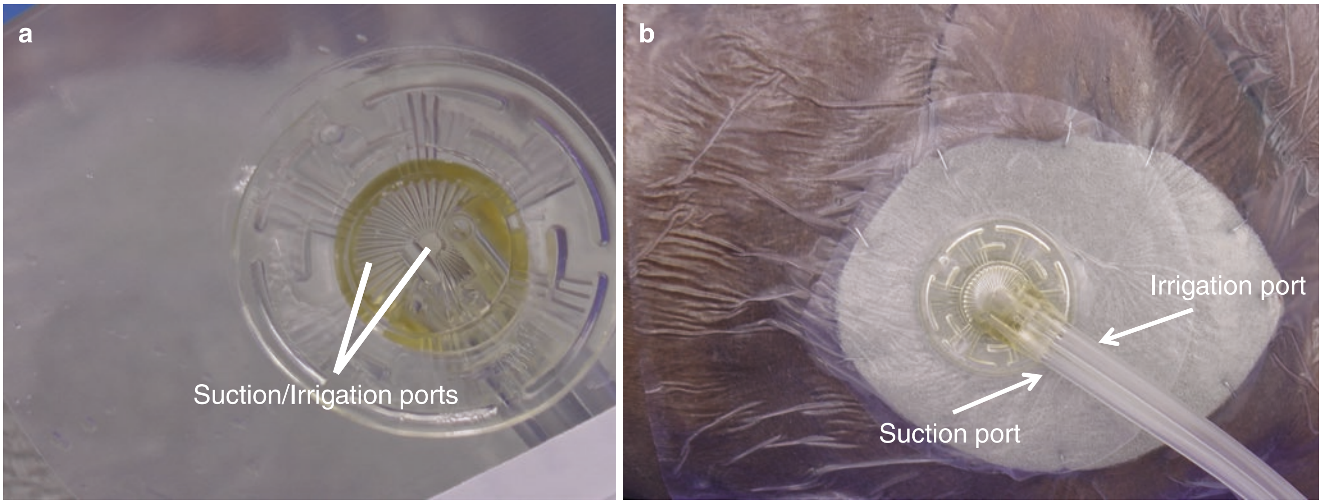


Fig. 29.5 The suction pad has a built in irrigation port (**a**). The suction/irrigation port is applied to the quarter size hole created (**b**). Alternatively, for larger wounds, separate irrigation and suction catheters may be used

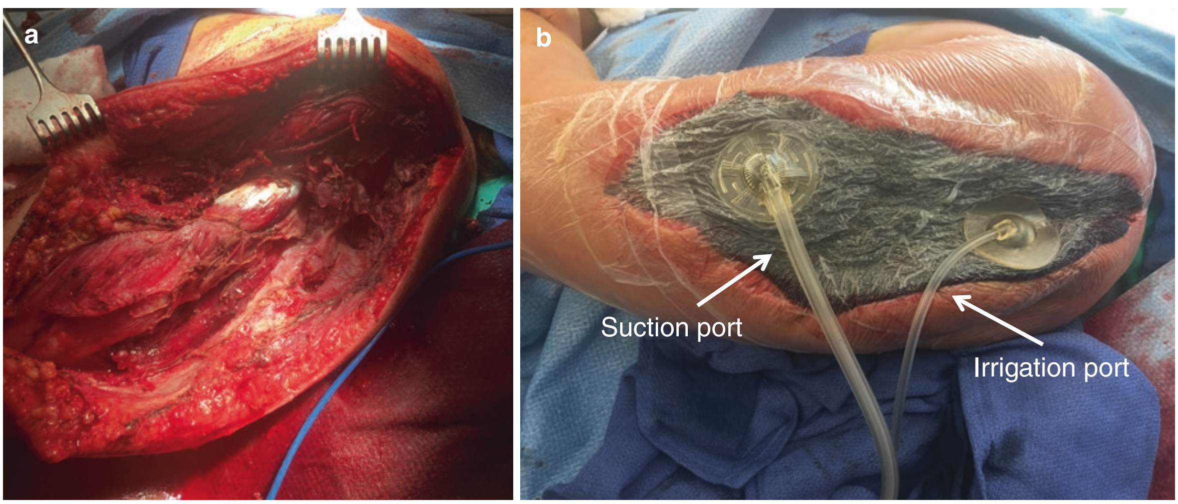


Fig. 29.6 Large upper extremity wound after debridement for NSTI (**a**) Veraflow system in place with separate irrigation and suction ports with the suction port placed in the dependent position (**b**)

Fig. 29.7 The base unit for the veraflow system. The fill assist button allows an initial determination of instillation volume (A). This volume is then entered into the instill volume section (B), along with the soak time (C), and time of and pressure of negative pressure therapy between instillation cycles (D, E)

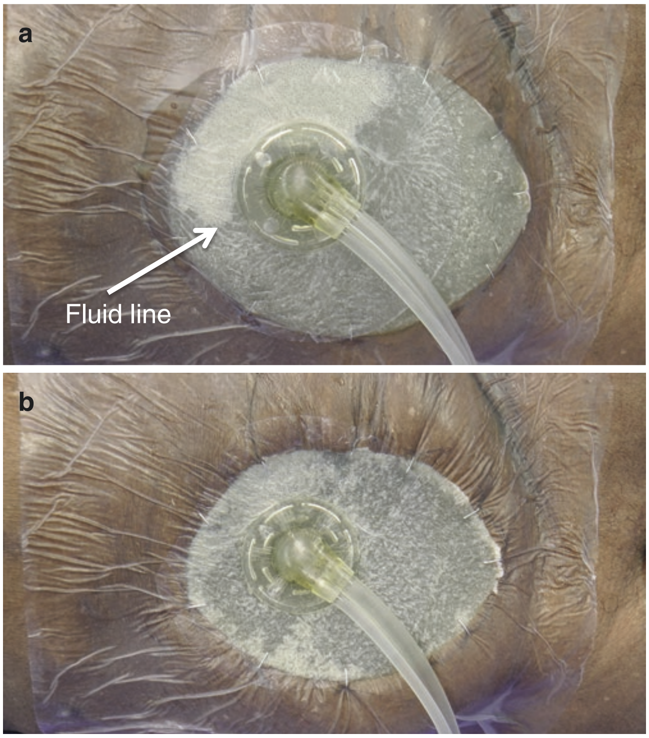


Fig. 29.8 The volume of irrigation instilled can be measured using the fill assist application on the base unit. The appropriate volume for irrigation volume is determined when the sponge changes color during initial filling (**a**). Once installation time is complete, the irrigant is suctioned out of the wound using the negative pressure therapy (**b**)

29.5 Bridging Adjacent Wounds

- Protect normal skin between the wounds with transparent adhesive drape.
- Place the usual foam over the wounds.
- Bridge the wounds with a strip of foam placed over the protective covering.
- Cover all foams with transparent adhesive drape.
- Apply suction/irrigation pad over the bridge, so that infected material from one wound is not drawn to the other wound (Fig. 29.9).
- Do not bridge infected with non-infected wounds.

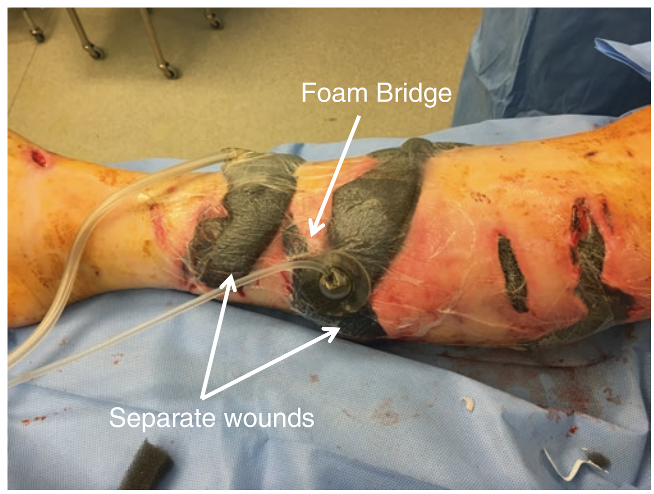


Fig. 29.9 Multiple leg wounds from a dog bite treated with the Veraflo system using the bridging technique

29.6 Maintenance of VAC Instillation Therapy

- Monitor VAC for any bleeding. Stop negative pressure therapy if there is bleeding, the patient becomes hypotensive, or the hemoglobin drops.
- Change VAC dressing every 3–4 days. In severe infections, a more frequent VAC change may be needed.
- Replace the collection canister when it is full.
- Replace the VAC irrigation system with a regular VAC when the infection clears.

29.7 Tips and Pitfalls

- Never apply NPWT in the presence of incomplete hemostasis due to the risk of severe bleeding.
- Never apply black foam directly over exposed vessels, nerves, or viscera. Protect these structures with Vaseline gauze before applying the foam.

Part VII

Abdomen

30 Diagnostic Peritoneal Aspiration/Lavage

Caroline Park and Lydia Lam

30.1 General Principles

- Diagnostic peritoneal aspiration (DPA) refers to the insertion of a catheter in the peritoneal cavity and aspiration of any fluid. Diagnostic peritoneal lavage (DPL) involves infusion of normal saline, lavage of the cavity, and macroscopic and microscopic evaluation of the returned fluid.
- DPA and DPL have largely been replaced by CT scan and abdominal ultrasound. However, in select cases it can provide quick information about intraperitoneal bleeding or infection.
- The most common trauma indication for DPA/DPL is suspicion of intraperitoneal bleeding in a hemodynamically unstable patient with a negative or equivocal ultrasound, who cannot undergo CT scan evaluation.
- DPA/DPL might be useful in selected unstable ICU patients with suspected peritonitis or who otherwise cannot be safely transferred for CT scan evaluation.
- There is evidence that the DPA is as sensitive as DPL in identifying clinically significant intraperitoneal bleeding.
- DPA/DPL does not identify retroperitoneal bleeding.

30.2 Contraindications for DPA/DPL

- Previous abdominal operations, coagulopathy, and morbid obesity. These are relative contraindications due to the high risk of iatrogenic injury, bleeding or technical difficulty, respectively.

30.3 Relevant Surgical Anatomy

This includes the following layers of the abdominal wall:

- Skin
- Subcutaneous fat
- Linea alba
- Peritoneum

30.4 Open Vs. Closed DPA/DPL

DPA and DPL are most often performed via closed, Seldinger technique. The open technique (i.e., under direct vision) should be performed in patients with previous laparotomy or current advanced pregnancy to avoid inadvertent injury.

C. Park · L. Lam (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: Lydia.lam@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_30

30.5 Equipment

The commercially available kits can be used for both DPA and DPL. These kits usually include (Fig. 30.1):

- 5 mL syringe with 1% lidocaine with epinephrine.
- Chlorhexidine or betadine skin preparation.
- 11 blade.
- 5 or 10 mL syringe with 18 g needle.
- Guidewire.
- Peritoneal catheter. A close-up of a peritoneal catheter is provided in Fig. 30.2a, b.
- Intravenous tubing with Luer Lock connection.

A warm 1 L 0.9% sodium chloride solution must be added separately if performing DPL.

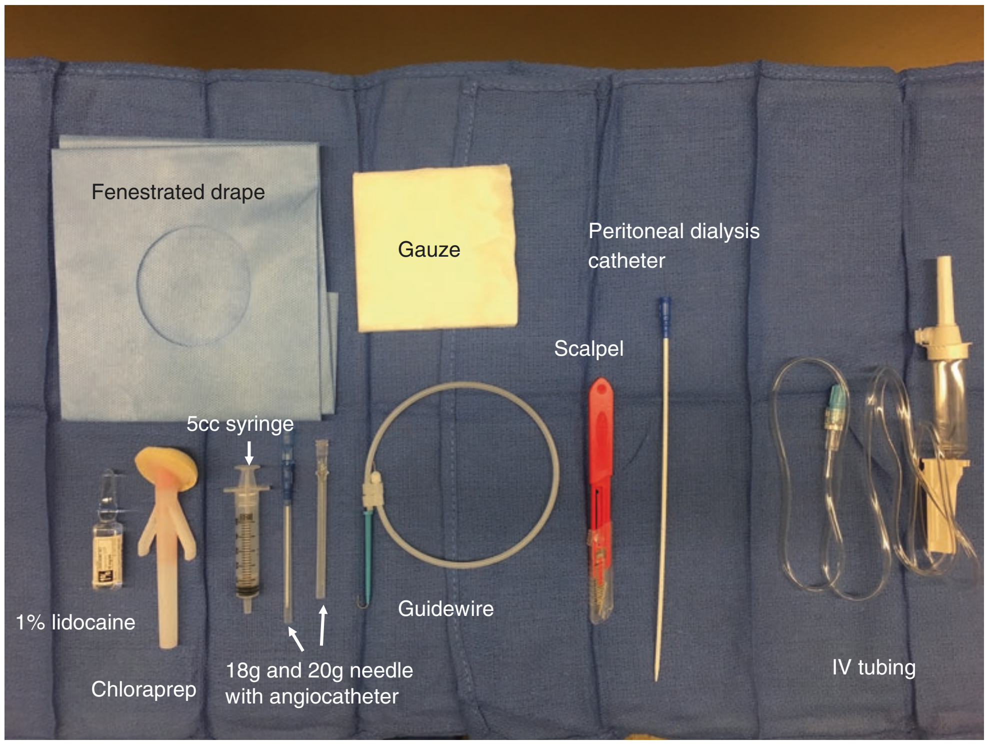


Fig. 30.1 Standard DPA and DPL equipment. These kits generally include a chlorhexidine or betadine prep, sterile drapes and gauze, 1% lidocaine, scalpel, 18 g and 20 g needle (with angiocatheter), 5 or 10 cc syringe, guidewire, peritoneal catheter, and IV tubing with Luer Lock connection

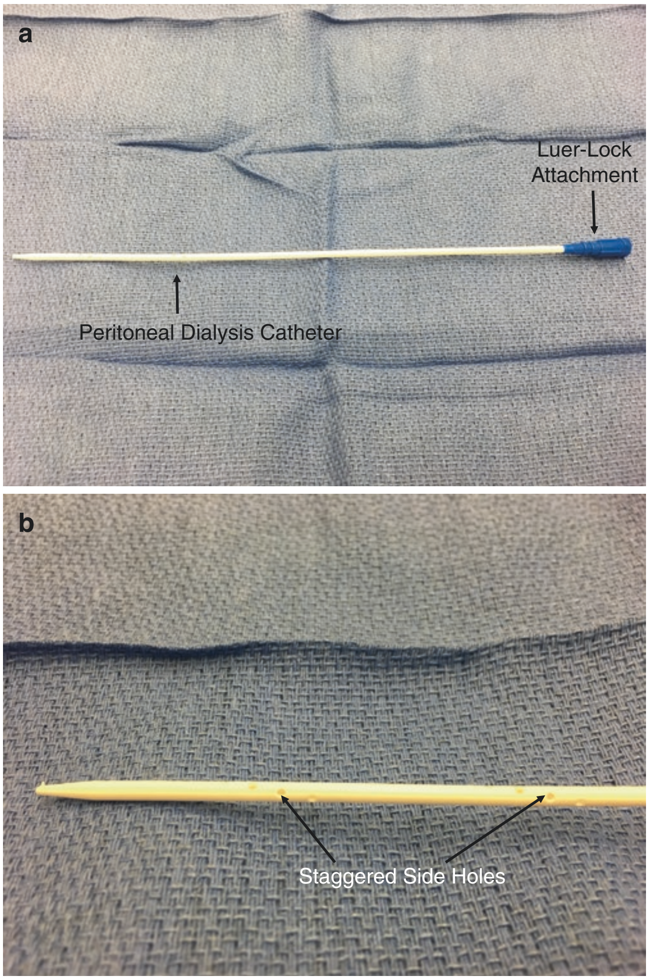


Fig. 30.2 (**a**) Peritoneal dialysis catheter. (**b**) Close-up of peritoneal dialysis catheter

30.6 Positioning

Patients should be in the supine position

- A Foley catheter should be placed to decompress the bladder.
- A nasogastric or orogastric tube should be placed and left to continuous suction to decompress the stomach.
- In gravid patients or patients with suspected pelvic trauma, approach both aspiration and lavage via supra-umbilical incision.

30.7 Seldinger Or "Closed" Technique: DPA

- Sterile preparation of the anterior abdomen with chlorhexidine or betadine.
- Apply a fenestrated drape or square off with four blue towels with the umbilicus exposed, allowing for 4 cm of exposure above and below (Fig. 30.3).
- Create a 0.5 cm vertical incision below the umbilicus with an 11 blade. The incision should be made above the umbilicus in advanced pregnancy or in patients with suspected severe pelvic fractures. In Fig. 30.4 we present a patient with suspected pelvic trauma and proceed with a supraumbilical incision. A curved hemostat may be used to dissect down to the fascia in obese or muscular patients (Fig. 30.5).
- Attach an 18 g needle to 5 or 10 cc syringe, and insert into the peritoneum, with a slight angle, pointing down toward the pelvis. Two "pops" should be felt during insertion of the needle: one during penetration of the fascia and a second one during penetration of the peritoneum (Fig. 30.6a,b).
- Aspirate content.
  – If it contains gross blood, bile, or stool, the study is positive and terminated and the patient taken to the operating theater (Fig. 30.7).
  – If no aspiration of gross blood or other fluids, remove syringe, and thread the guidewire through the needle, in a direction slightly toward the pelvis. The wire should not encounter any resistance (Fig. 30.8a,b).
  – Remove the needle, and insert a peritoneal dialysis catheter over wire with a slight "twisting" motion, pointing down toward the pelvis along the abdominal wall to avoid intestinal injury. No significant resistance should be encountered (Fig. 30.9a,b).
  – Remove the wire and connect a 10 mL syringe to the catheter and aspirate. If blood or intestinal contents or other suspicious fluids are aspirated, the study is positive, and the procedure is terminated (Fig. 30.10a,b).
  – If the aspiration is negative, the catheter is removed, and the skin is stapled or sutured (Fig. 30.11).

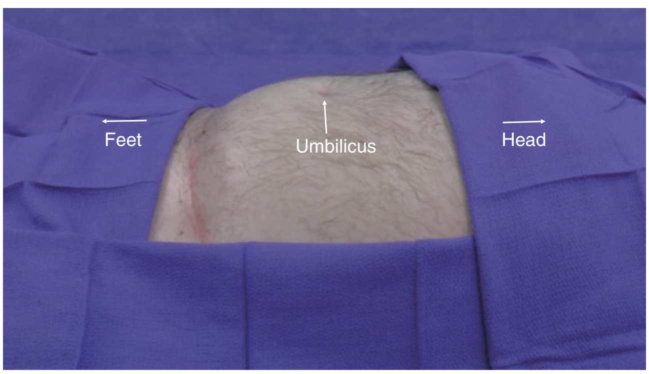


Fig. 30.3 Patient in the supine position. The periumbilical area has been sterilely prepped and draped with blue towels and exposed for purposes of demonstrating the anatomy. A fenestrated drape may also be used. The direction of the pelvis and head is demonstrated

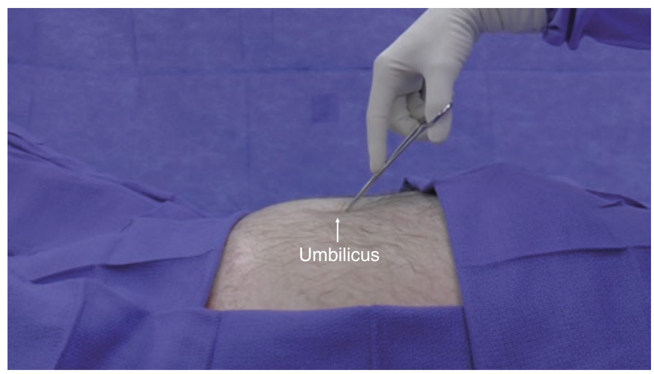


Fig. 30.5 A curved hemostat may be used to dissect down to the fascia in obese or muscular patients.

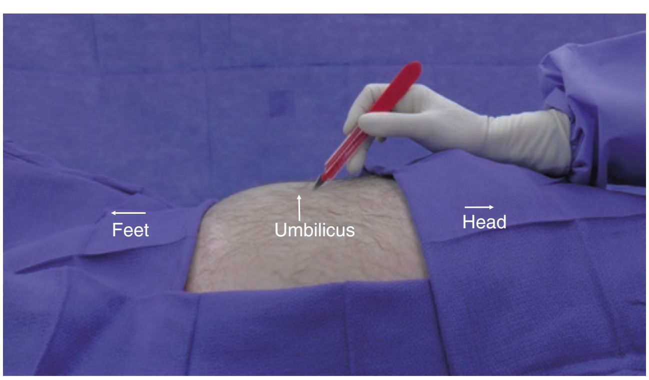


Fig. 30.4 Apply a fenestrated drape or square off with four blue towels with the umbilicus exposed, allowing for 4 cm of exposure above and below. Create a 0.5 cm vertical incision below the umbilicus with an 11 blade or above the umbilicus in advanced pregnancy or in patients with suspected severe pelvic fractures

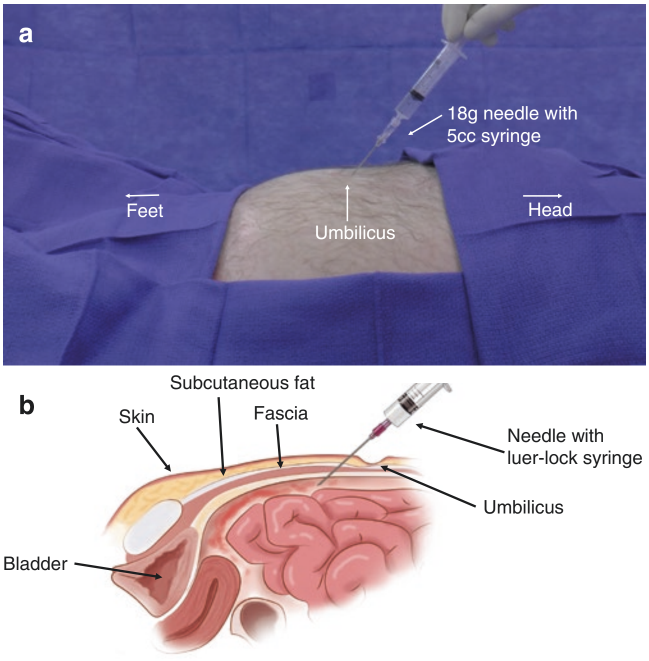


Fig. 30.6 (**a**) Attach an 18 g needle to 5 or 10 cc syringe, and insert into the peritoneum, with a slight angle, pointing down toward the pelvis. Two "pops" should be felt during insertion of the needle: one during penetration of the fascia and a second one during penetration of the peritoneum. (**b**) Cross-sectional view of pelvis. Needle with Luer Lock syringe is placed below the umbilicus (above the umbilicus in suspected pelvic trauma or pregnancy) and directed toward the pelvis—feel for two "pops" as the needle enters the fascia and peritoneum

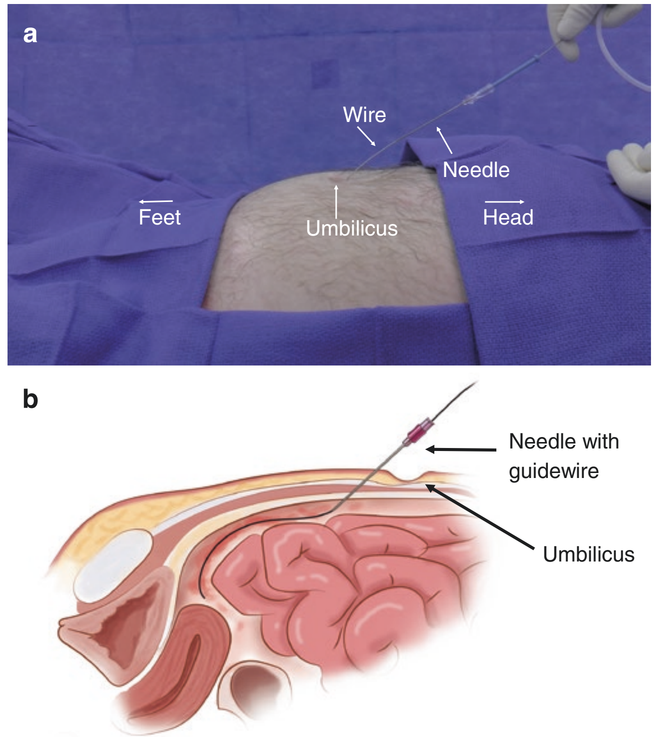


Fig. 30.8 (**a**) If no aspiration of gross blood or other fluids, remove syringe, and thread the guidewire through the needle, in a direction slightly toward the pelvis. The wire should not encounter any resistance. (**b**) Cross-sectional view of the pelvis with guidewire advanced through the needle

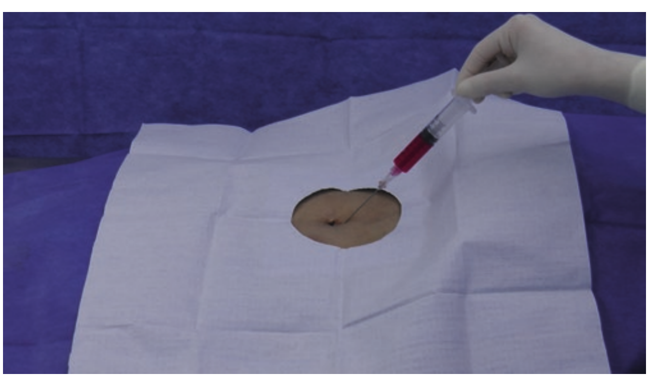


Fig. 30.7 Gently aspirate content. If the aspirate contains gross blood bile or stool, the study is positive and is terminated

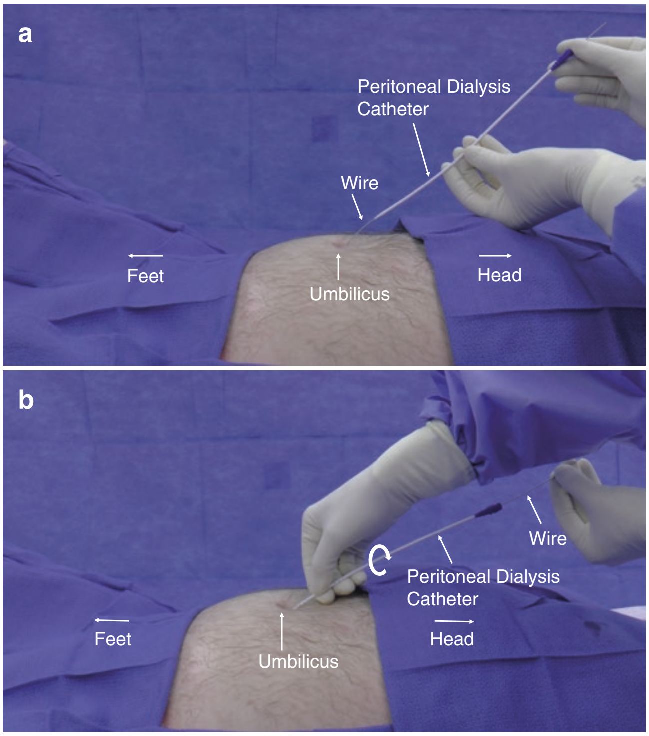


Fig. 30.9 (**a**) Insert a peritoneal dialysis catheter over the guidewire with a slight “twisting” motion, pointing down toward the pelvis. No significant resistance should be encountered. (**b**) Remove the needle, and replace a peritoneal dialysis catheter over the wire with a slight “twisting” motion, pointing down toward the pelvis and along the abdominal wall to avoid intestinal injury. No significant resistance should be encountered

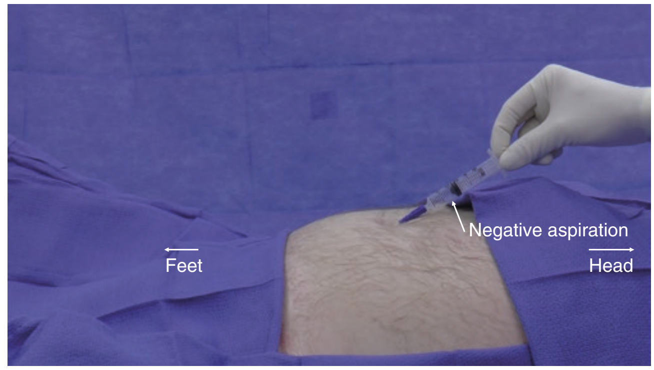


Fig. 30.11 If the aspiration is negative, the catheter is removed, and the skin is stapled or sutured closed with a nonabsorbable suture. Refer to next steps with saline lavage if proceeding with DPL

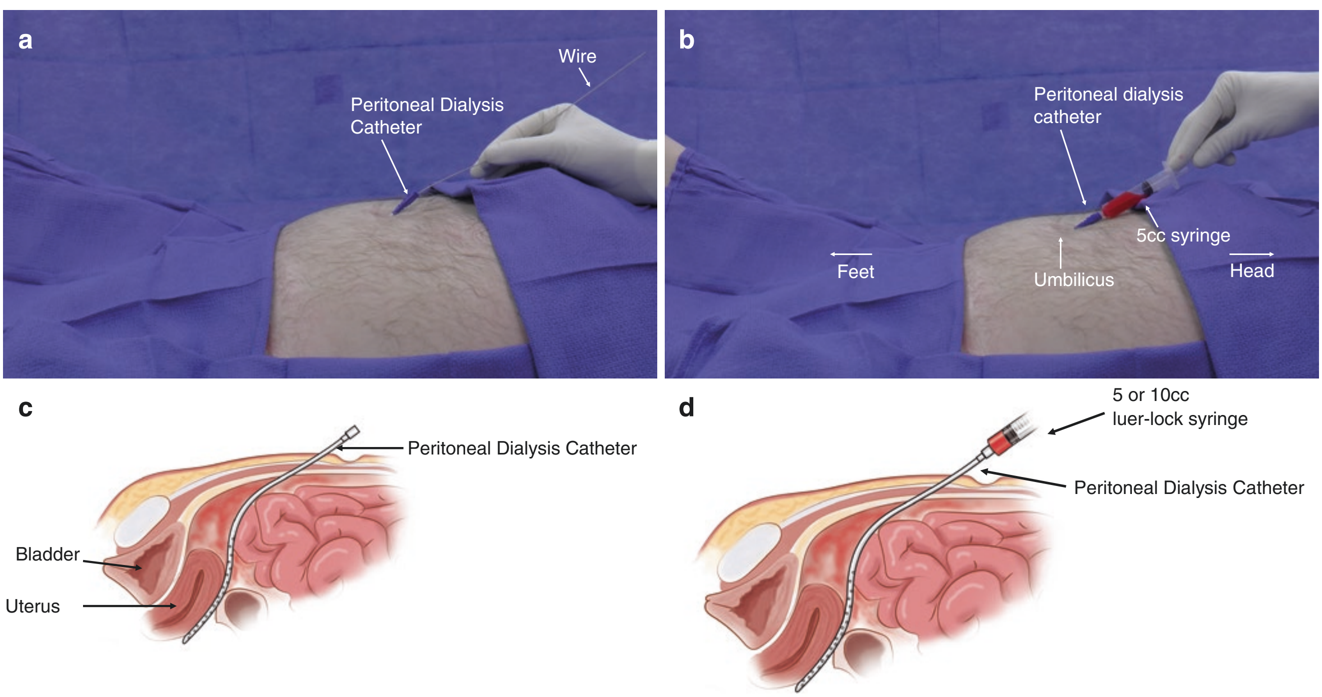


Fig. 30.10 (**a**) Complete insertion of the catheter over the guidewire. The wire is then removed. (**b**) A 10 mL syringe is connected to the catheter and aspiration is performed. If blood or intestinal contents or other suspicious fluids are aspirated, the study is positive, and the procedure is terminated. (**c**) Cross-sectional view of the pelvis with peritoneal dialysis catheter advanced over guidewire and directed into the pelvis and posterior to the bladder and uterus. (**d**) Cross-sectional view of the pelvis with aspiration of peritoneal dialysis catheter

30.7.1 Technique for DPL: Seldinger or "Closed" Technique

- A catheter is placed in the peritoneal cavity, using the technique described above for DPA.
- If the aspiration is negative, the intraperitoneal catheter is connected to intravenous tubing and 1000 mL of warm 0.9% sodium chloride. Rapidly infuse the 1000 mL (or 25 mL/kg in children) into the peritoneal space; this can be performed with a pressure bag or with manual pressure (Fig. 30.12).
- After completion of saline infusion, lower an empty drainage bag to ground level to allow for drainage by gravity. Allow the lavaged fluid to drain passively from the peritoneal cavity.
- Send fluid for laboratory tests: red cells, white blood cells, amylase, and creatinine, cultures in the appropriate cases.
- DPL is considered positive if:
  - RBC > 100,000/mm^3
  - WBC > 500/mm^3
  - High amylase (suspicious for pancreatic leak or pancreatitis)
  - High creatinine (suspicious for bladder rupture)
  - Initial aspiration of >10 mL of gross blood, succus, and stool

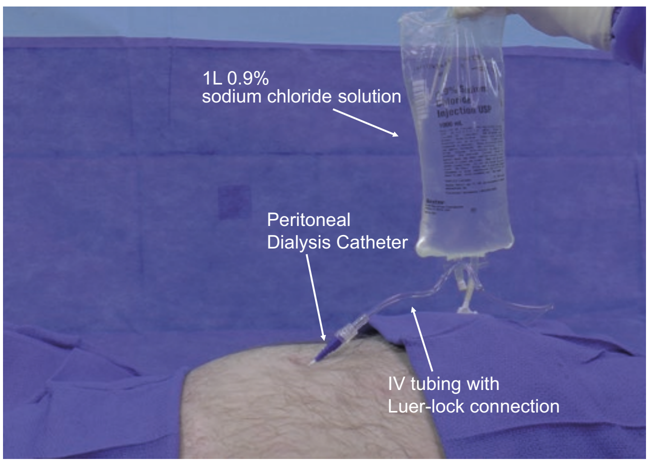


Fig. 30.12 If the aspiration is negative, the intraperitoneal catheter is connected to intravenous tubing and a 1000 mL bag of warm 0.9% of sodium chloride. Rapidly infuse the 1000 mL into the intraperitoneal space (or 25 mL/Kg in children)

30.8 Open Technique for DPA/DPL

30.8.1 Equipment

- The above equipment for DPA/DPL
- Two Kocher clamps
- One needle driver
- One Metzenbaum scissors
- Prolene suture or skin stapler

30.8.2 Techniques

- Similar sterile preparation and 1–2 cm incision below the umbilicus (or above in suspected pregnancy or pelvic trauma).
- Spread the subcutaneous tissues down to the linea alba with curved hemostat.
- Elevate the linea alba between two Kocher clamps.
- Incise longitudinally between Kocher clamps with an 11 blade.
- Incise the peritoneum with Metzenbaum scissors.
- Run a purse-string suture of the fascial defect with 0-vicryl or 0-prolene; do not tie down yet.
  - Insert peritoneal dialysis catheter at an angle pointing toward the pelvis and anterior to the abdominal wall to avoid intestinal or pelvic vessel injury.
  - Angle the syringe toward the pelvis, maintaining negative pressure on the syringe.
  - Maintain the same angle, and advance a floppy guidewire through the needle.
  - Thread a diagnostic peritoneal dialysis catheter over the guidewire via Seldinger technique and direct toward the pelvis posterior to the bladder.
  - Apply a 5 or 10 mL syringe with Luer Lock connection and aspirate (Fig. 30.13).
- After completion of the DPA/DPL, the catheter is removed, and the purse-string suture is tied.
- Close the skin with staples or absorbable suture.

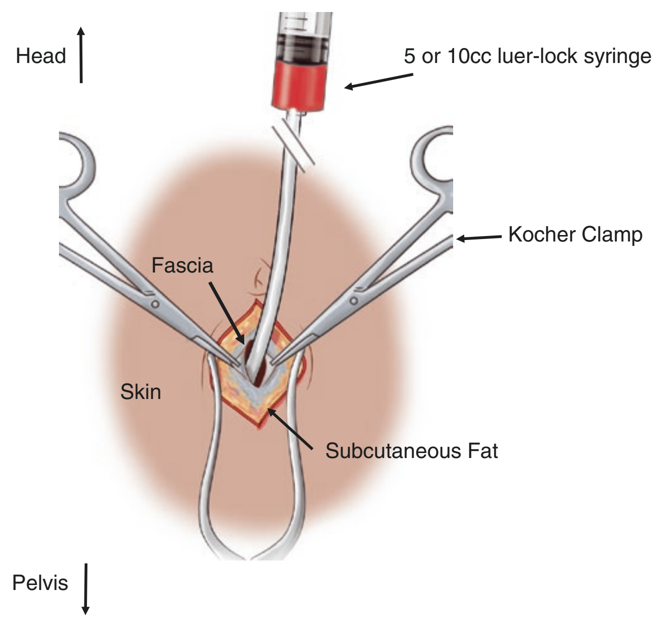


Fig. 30.13 Open technique for DPA/DPL: spread tissues down to the linea alba, and elevate the fascia between two Kocher clamps. Incise the fascia and peritoneum sharply, and then direct the DPA/DPL catheter through the fascial defect toward the pelvis

30.9 Limitations

The accuracy of DPA and DPL is often operator dependent and can be affected by the patient's body habitus (i.e., morbidly obese, previous laparotomy, or peritonitis).

- False positives may be a result of improper technique, such as insertion of the catheter into an intramuscular or pelvic hematoma into a solid organ (i.e., low-lying liver or spleen with organomegaly) or a vessel (i.e., varix in cirrhotic patients).
- False negative may be the result of extraperitoneal placement of the catheter.
- Retroperitoneal bleeding cannot be identified by DPA/DPL.
- Potential injury to intra-abdominal or pelvic organs (i.e., hollow viscus, bladder, stomach, vessel, pregnant uterus).

30.10 Tips and Pitfalls

- Do not use force to advance the guidewire or the peritoneal catheter if you encounter resistance. Most likely, the needle or guidewire is extraperitoneal! Withdraw and reinsert the needle. Feel for the "two pops" as you enter the fascia and peritoneum.

Percutaneous Endoscopic Gastrostomy

31

Chrissy Guidry, Meghan Lewis, and Travis Polk

31.1 Surgical Anatomy

31.1.1 External Landmarks

- Surface anatomic landmarks include the abdominal midline, the costal margin, and the umbilicus. The site of insertion lies midway between the umbilicus and the costal margin and with care taken to remain at least 2–3 fingerbreadths from the rib margin (Fig. 31.1).

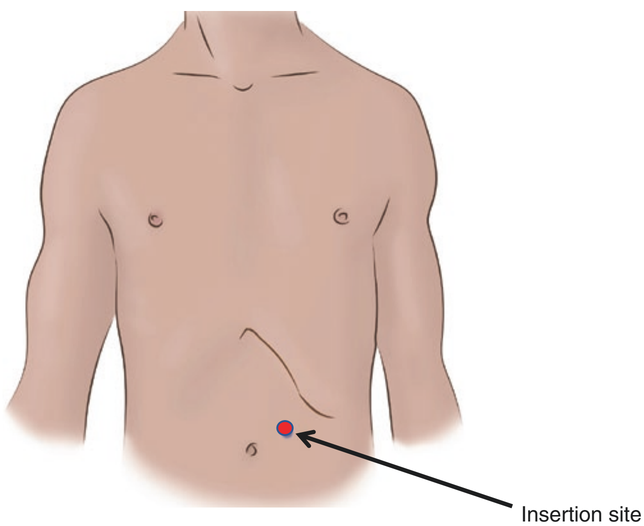


Fig. 31.1 Area of insertion in left upper quadrant. Landmarks include the abdominal midline, left costal margin, and umbilicus

C. Guidry · M. Lewis (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: meghan.lewis@med.usc.edu

T. Polk
Medical Corps, U. S. Navy, Washington, DC, USA

Uniformed Services University, Bethesda, MD, USA

Navy Trauma Training Center, LAC+USC Medical Center, Los Angeles, CA, USA

31.1.2 Stomach and Other Intra-Abdominal Structures

- The distal gastric fundus underlies the insertion site and will oppose the underside of the abdominal wall once the stomach is fully insufflated with air.
- The colon or small bowel may be transposed between the anterior wall of the stomach and the abdominal wall. This is more common in patients with adhesions from previous surgery or a redundant transverse colon.

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_31

31.2 General Principles

- Indications for gastrostomy include:
  – Long-term feeding access in severely ill or injured patients.
  – Long-term feeding access in patients with swallowing difficulty.
  – Palliative decompression in malignant obstruction (unusual).
- Relative contraindications to PEG may include:
  – Obstruction of the esophagus/airway which may prevent introduction or removal of the feeding tube (i.e., esophageal tumors, strictures, etc.).
  – Difficulty confirming placement site with transillumination or direct motion.
  – Previous abdominal surgeries near gastrostomy site.
  – Other conditions which would contraindicate endoscopic or surgical procedures.
- Consent from the patient or family member should be obtained whenever possible. Risks may include:
  – Injury/perforation to the aerodigestive tract from endoscopy.
  – Injury/perforation to the colon or small bowel.
  – Leakage of gastric contents.
  – Tube dislodgement.
  – Pneumoperitoneum.
  – Peritonitis/sepsis.
  – Wound complications at stoma site (infection/necrosis).
  – Gastrocolic fistula.
  – Persistent gastrocutaneous fistula.
  – Small bowel obstruction.
- While bedside PEG is a safe and effective procedure for the majority of patients, a variety of other enteral access techniques are also available and may be preferable in a given patient. These include radiographically guided percutaneous gastrostomy or feeding jejunostomy tubes, as well as both open and laparoscopic approaches to gastrostomy and feeding jejunostomy.
- Two equally effective standard PEG procedures (“push” vs. “pull”) are routinely employed. The choice of procedure is usually dictated by individual surgeon and institution preferences. The commonly used “pull” technique will be the primary focus of the remainder of this chapter.

31.3 Instruments

- Multiple commercially available kits exist for PEG placement. The operator should ensure familiarity with the specific product prior to use.
- General contents of a "pull" PEG kit include (Fig. 31.2):
  - 25 gauge needle for local anesthetic infiltration.
  - 14 gauge angiocatheter needle for accessing the stomach.
  - 10 cc syringe.
  - Looped insertion wire.
  - Scalpel.
  - PEG tube with loop and dilator at distal end and rubber dome bumper on gastric end (typically 20 French or 24 French).
  - Standard endoscopic snare.
  - External tube bumper, tube clamp, and other accessories.
- Additional equipment not included in the kits:
  - Sterile drapes, gloves, and gown.
  - Local anesthetic.
  - Video esophagogastroduodenoscope and tower.
  - Appropriate airway and monitoring equipment.

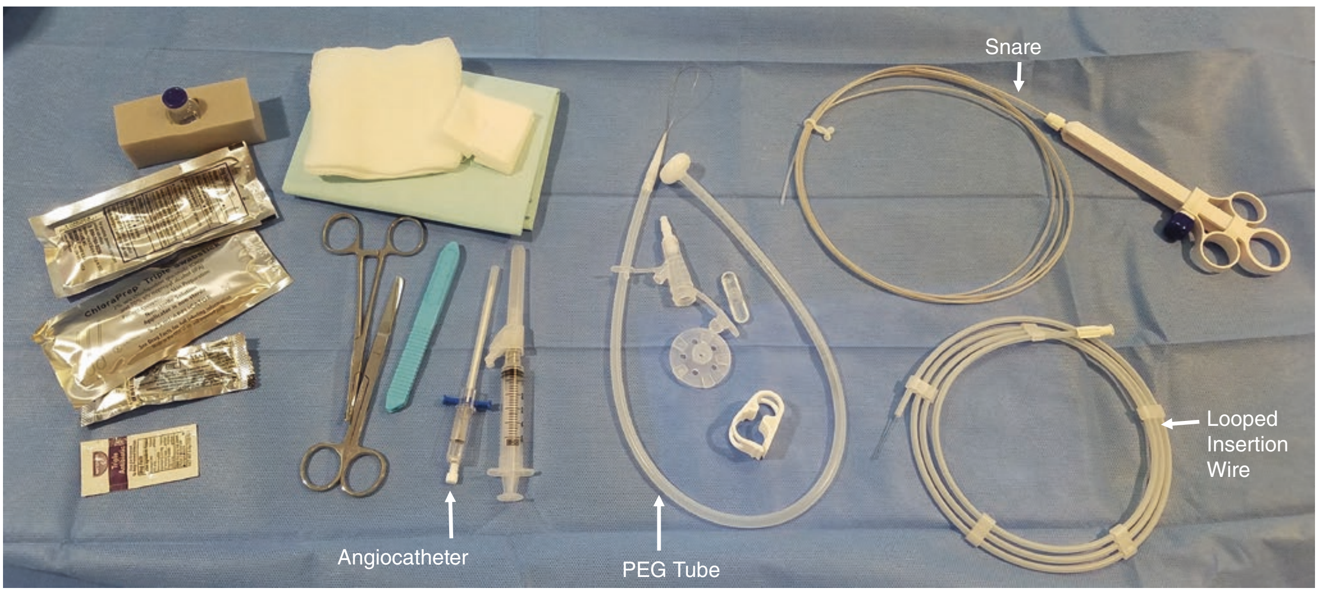


Fig. 31.2 Standard "pull" PEG kit

31.4 Technique

31.4.1 Anesthesia and Patient Preparation

- PEG may be performed under general anesthesia or deep sedation when endotracheally intubated in the intensive care unit or operating room. Additionally, it may be safely performed using local anesthesia and moderate sedation in patients that are not intubated.
- For the ICU patient, the procedure is frequently combined with tracheostomy (either bedside percutaneous or operative open approach).
- Current endoscopy guidelines recommend the administration of a single preoperative dose of an intravenous antibiotic, such as a cephalosporin, prior to PEG.
- The patient is positioned supine and a bite block is utilized to protect the endoscope.
- Appropriate monitoring, airway, and emergency equipment are verified.

31.4.2 Site Selection

- The endoscope is introduced into the mouth and passed down the esophagus in the usual fashion. The stomach is fully insufflated, and the esophagus, stomach, and duodenum are explored, as indicated.
- The abdominal wall is transilluminated with light of gastroscope to ensure safe placement location. (Note: This often requires dimming the room lights and closing any window shades, in order to reduce ambient light.) (Fig. 31.3)
- The site of insertion is located by applying deep finger pressure in the region of transillumination. A clear indentation of the anterior gastric wall should be visible (Fig. 31.4).

Fig. 31.3 "Glow" from endoscopic transillumination

Fig. 31.4 Endoscopic view of the anterior gastric wall during indentation

31.4.3 Tube Placement

- Infiltrate local anesthetic subcutaneously into the skin of the puncture site.
- Make a 1 cm skin incision at the selected site using a #11 scalpel (Fig. 31.5).
- Insert the 14 gauge angiocatheter through incision under direct endoscopic vision (Fig. 31.6).
- A syringe with sterile saline or water may be attached to the needle and aspirated during insertion. The surgeon will watch the syringe for air bubbles, while the assistant watches for entry into the gastric lumen. If air appears in the syringe before the needle is visible, there should be concern for entry into another hollow viscus such as the colon, and the procedure should be aborted.
- Place the endoscopic snare into the stomach, and open it around the inserted angiocatheter/needle.
- Remove the needle from the angiocatheter, and insert the looped end of the insertion wire into the abdomen through the cannula (Fig. 31.7).
- Grasp the wire with the snare (Fig. 31.8).
- While holding the wire tightly with the snare, remove the gastroscope from the patient's mouth, and retrieve the wire.
- Secure the suture loop on the end of the PEG tube to the looped wire exiting the mouth by passing the loops through each other (Fig. 31.9).
- The PEG tube should then be advanced in an antegrade fashion by pulling on the wire that exits the abdominal wall.
- Care is taken to gently guide the tube through the mouth, and the tube is followed by the gastroscope to confirm appropriate placement. If passage of the gastroscope was initially difficult, it is sometimes helpful to grasp the end of the tube with the snare in order to facilitate following the tube back into the stomach (Figs. 31.10 and 31.11).
- The gastroscope remains in the stomach until the tube is secured. The tube should be snug but spin freely and not be under significant tension (Fig. 31.12).
- The depth at the skin should be noted and annotated for future reference, and a suture tie, tape, or Band-Aid can be placed either on or distal to the external bumper to prevent migration (Fig. 31.13).
- The dilating tip is cut off, and the PEG tube is trimmed to approximately 12 in. in length. The external bumper, clamp, and dual port feeding adapter are attached (Figs. 31.14 and 31.15).
- The tube may be left to gravity drainage with a Foley bag for 6–24 h post procedure followed by reinitiation of enteral feeding.

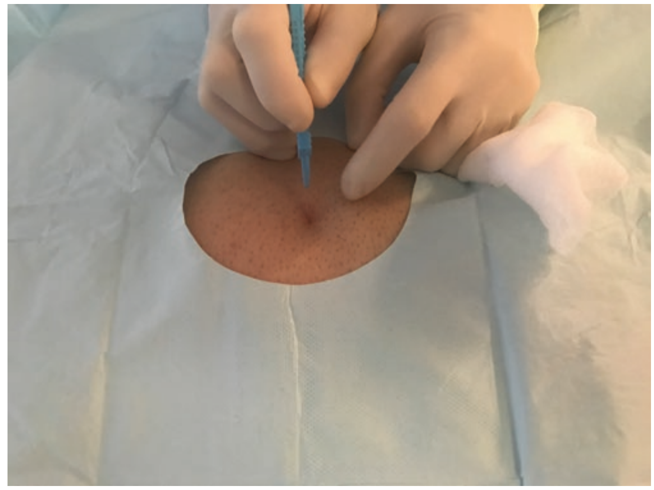


Fig. 31.5 Incision

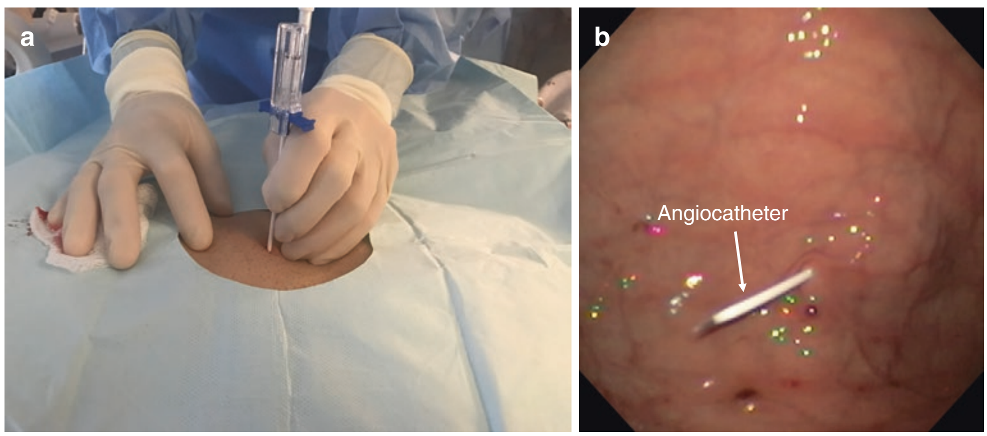


Fig. 31.6 Insertion of angiocatheter into the gastric lumen. (**a**) External view, (**b**) endoscopic view

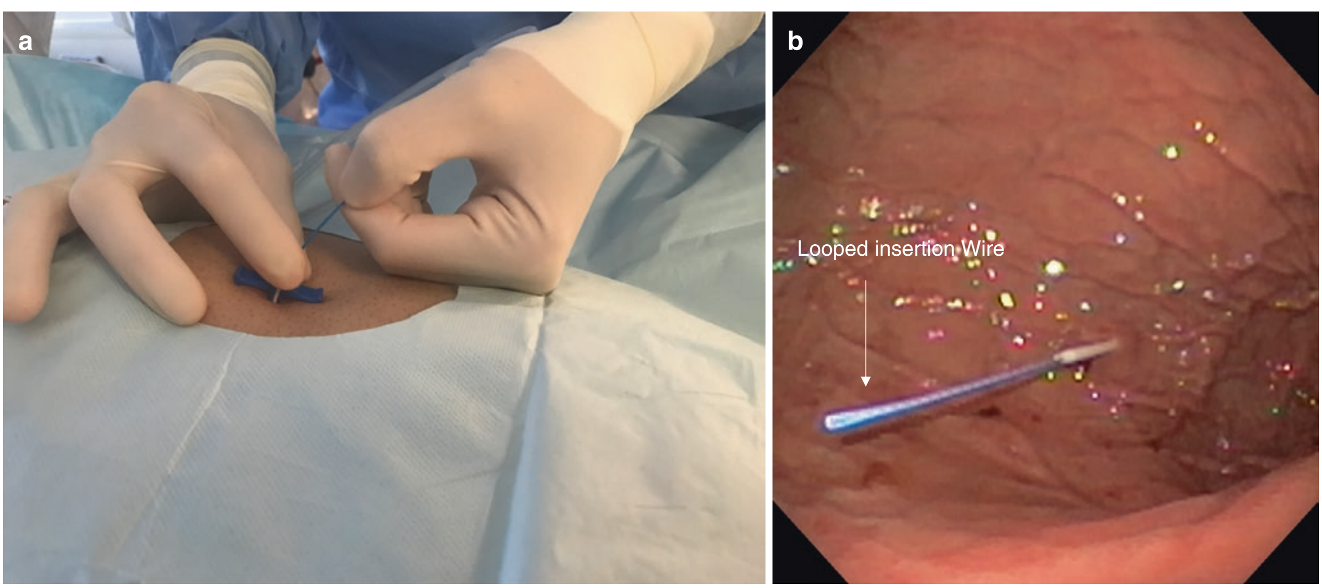


Fig. 31.7 Wire is passed through angiocatheter, (**a**) external view, (**b**) endoscopic view

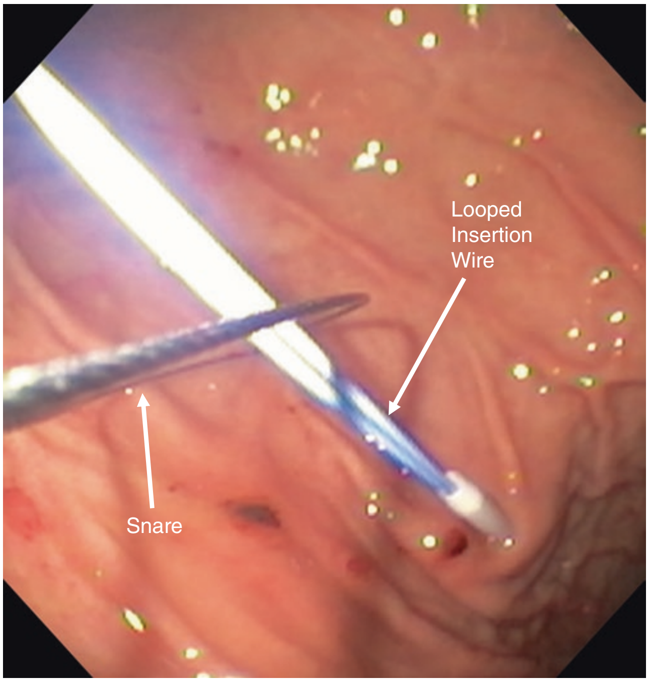


Fig. 31.8 Endoscopic snare is used to grasp the wire

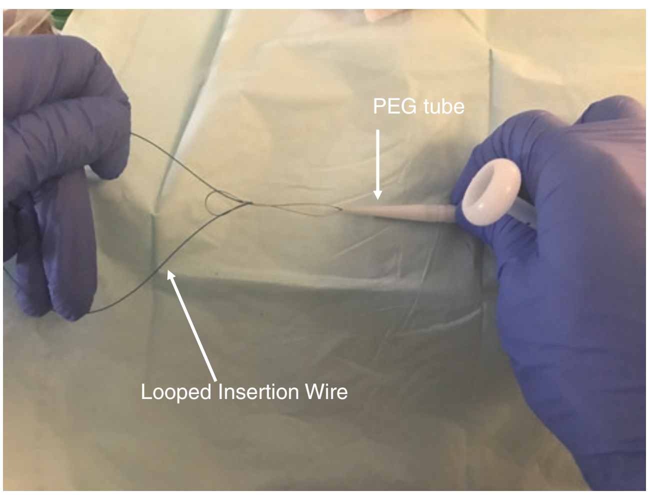


Fig. 31.9 After removing the wire with gastroscope from the mouth, the gastrostomy tube and wire are looped together

Fig. 31.10 Internal bumper of PEG tube may be grasped with snare to ease endoscope passage

Fig. 31.11 Wire is pulled antegrade advancing PEG tube through incision. Dilating tip is seen exiting the skin

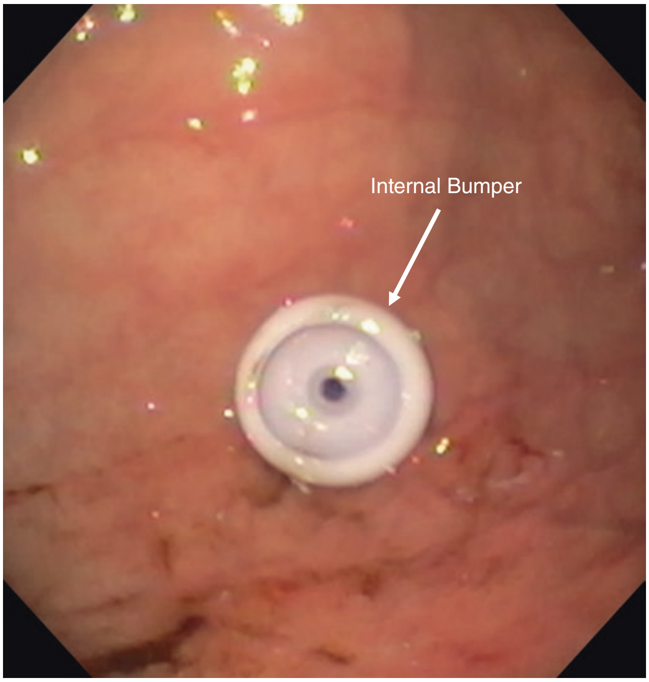


Fig. 31.12 Endoscopic view of properly inserted tube

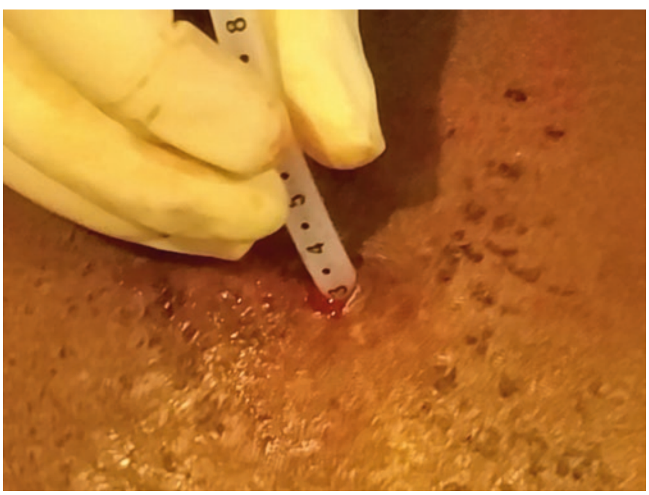


Fig. 31.13 Tube depth at skin level should be annotated for later reference

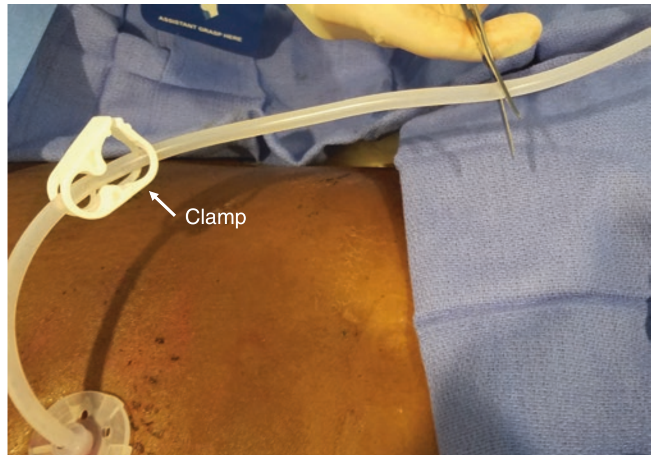


Fig. 31.14 The PEG tube is trimmed to appropriate length

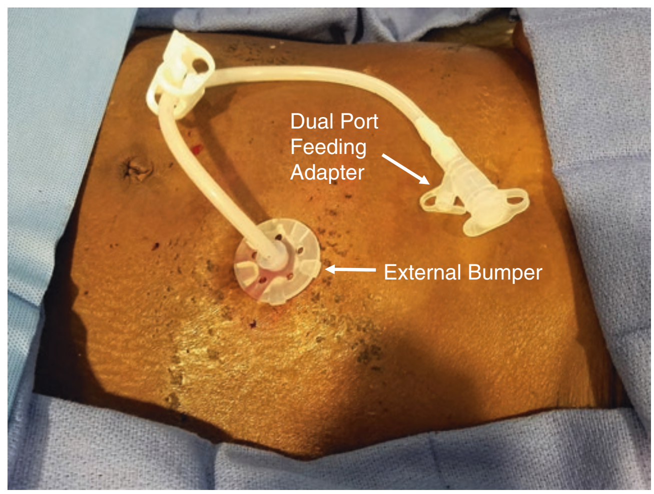


Fig. 31.15 External bumper, tube clamp, and feeding adapter are secured in placed, and the procedure is complete

31.4.4 Removal

- PEG tubes should be left in place for at least 6 weeks prior to consideration of removal in order to ensure adequate gastric adhesion to the abdominal wall and tract formation.
- Tubes may be removed by traction or endoscopic retrieval of the internal bumper.

31.5 Tips and Pitfalls

- If there is suspicion for tube or internal bumper malposition or dislodgment, tube feeds should be held and intraluminal position should be verified with a contrast study. While this may be salvageable with fluoroscopic or endoscopic tube replacement in the stable patient, one must have a low threshold for operative exploration and repair.
- Undue traction on the tube or overtightening may cause tube site erosion and contribute to site infection or tube leakage.
- In rare cases, persistent gastrocutaneous fistula will persist following tube removal and may require surgical repair.
- If severe diarrhea occurs immediately upon initiation of tube feeding, one must consider the possibility of an iatrogenic gastrocolic fistula.

32 Balloon Tamponade for Variceal Hemorrhage

Brian T. Lee and Jeffrey A. Kahn

32.1 Introduction

- Variceal hemorrhage remains a major cause of mortality in those with portal hypertension. Varices can occur in the esophagus, usually distally, or stomach, usually in the fundus.
- Endoscopy with hemostasis technique is the mainstay treatment for esophageal variceal bleeding, while portosystemic shunt placement is the treatment for gastric variceal bleeding. However, these procedures require resuscitation and strategic planning prior to initiation.
- Balloon tamponade remains a useful technique in temporarily arresting hemorrhage until more definitive treatment can be pursued.

32.2 Surgical Anatomy

- The esophagus consists of the upper and lower esophageal sphincters and is approximately ~25 cm long. Varices usually form in the distal third of the esophagus.
- In the stomach, junctional varices from the esophagus tend to form in the cardia and fundus, while isolated gastric varices can form in the fundus and antrum.

32.3 General Principles

- The indication for balloon tamponade should not be for definitive hemostasis but as a temporizing measure until definitive therapy can be pursued via endoscopy, interventional radiology, or surgery.
- Insertion should be performed in the intensive care unit given the high risk of hemodynamic instability.
- This is not a sterile procedure. However, a gown, a mask, and eye protection are recommended as a precautionary method in case of hematemesis.

B. T. Lee · J. A. Kahn (✉)
Keck School of Medicine of University of Southern California, Los Angeles, CA, USA
e-mail: Jeffrey.Kahn@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_32

32.4 Instruments

- Equipment necessary to perform this procedure should include a balloon tube, lubricant, 50 mL syringe, Kelly clamps, and tape. A traction device is also necessary to sustain tamponade; traditionally, a football helmet is used.
- Sengstaken-Blakemore tube (Fig. 32.1a)—Consists of three ports and both esophageal and gastric balloons. Gastric balloon is approximately 250 mL.
  – Ports: Gastric suction port, gastric balloon inflation port, esophageal balloon inflation port
  – Boyce modification: Additional tube in the proximal esophagus to decrease risk of aspiration
- Minnesota tube (Fig. 32.1b)—A modified version of the Sengstaken-Blakemore tube. Consists of four ports and both esophageal and gastric balloons.
  – Ports: Gastric suction port, gastric balloon inflation port, esophageal balloon inflation port, esophageal suction port (above esophageal balloon)
- Linton-Nachlas tube (Fig. 32.1c)—Consists of three ports and only one large gastric balloon that holds 600 mL of air.
  – Ports: Gastric suction port, gastric balloon inflation port, esophageal suction port
  – Preferred in gastric variceal bleeding

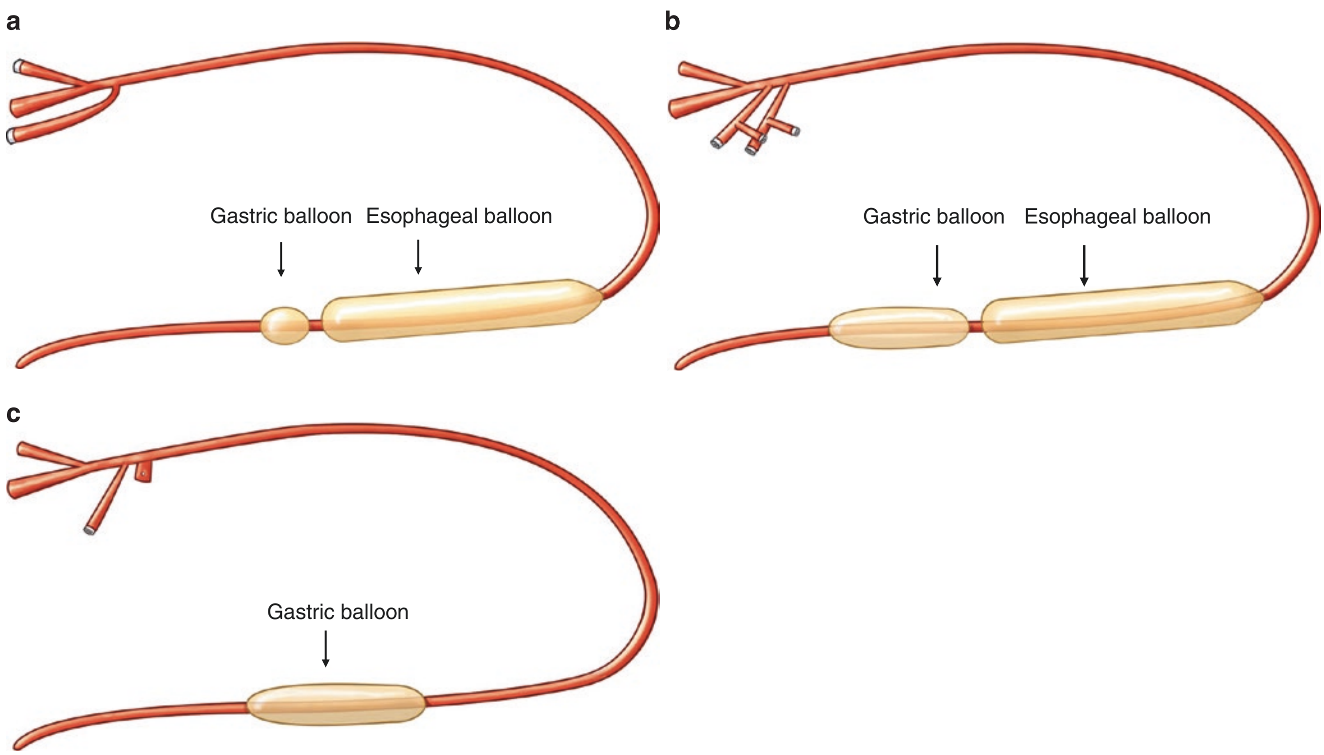


Fig. 32.1 (**a**) Sengstaken-Blakemore tube. Three ports include esophageal and gastric balloon ports and a gastric suction port. (**b**) Minnesota tube. Four ports include gastric suction port, gastric balloon inflation port, esophageal balloon inflation port, and esophageal suction port. (**c**) Linton-Nachlas tube. Three ports include gastric suction port, gastric balloon inflation port, and esophageal suction port

32.5 Positioning

- Airway protection is key. Preferably, the patient should be endotracheally intubated prior to balloon insertion. This will protect the airway from aspiration of blood along with secretions after balloon tamponade. This will also protect the airway from balloon insertion.
- Place the patient supine with the head of bed at 45° to assist with facilitation of balloon tube down the oropharynx into the digestive tract (Fig. 32.2).

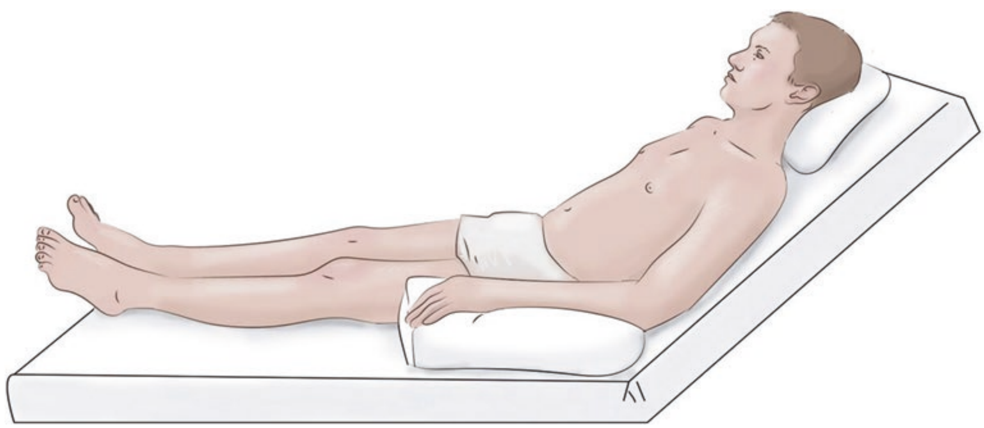


Fig. 32.2 The patient is placed supine with the head of bed at 45° to ease passage of tube into the esophagus

32.6 Insertion Techniques

1. Check patency of the balloons prior to insertion. Note which ports correspond to their respective parts of the tube.
2. Lubricate the tube.
3. Insert through the nostril past the oropharynx and esophagus and into the stomach. At least 50 cm should be passed to decrease risk of positioning in the esophagus.
4. Once placed, suction the balloon ports to remove all air.
5. Inflate the gastric balloon port with air, respective of the volume aliquoted by the manufacturer. A sound is usually auscultated over the left hypochondrium in accordance with inflation attempts, indicating proper positioning. Ensure proper placement of the tube given the risk of being kinked in the oropharynx or inflating the gastric balloon inside the esophagus.
6. Clamp the inflation port after each inflation attempt to ensure accurate measurement of air inflation. Use a Kelly clamp to close ports (Fig. 32.4).
7. Pull tube back to ensure tamponade of gastric balloon to the fundus.
8. Secure tube to traction device. The end of the tube can be fastened to the face guard of a helmet (Fig. 32.5). If a helmet is not available, a pulley system can be devised using a Kerlix dressing and a 1 to 2 pound object (i.e., a bag of 500 mL normal saline).
9. Imaging with X-ray to confirm position (Fig. 32.6).
10. In the setting that bleeding is not controlled, one can consider inflating the esophageal balloon, if available (Fig. 32.3).

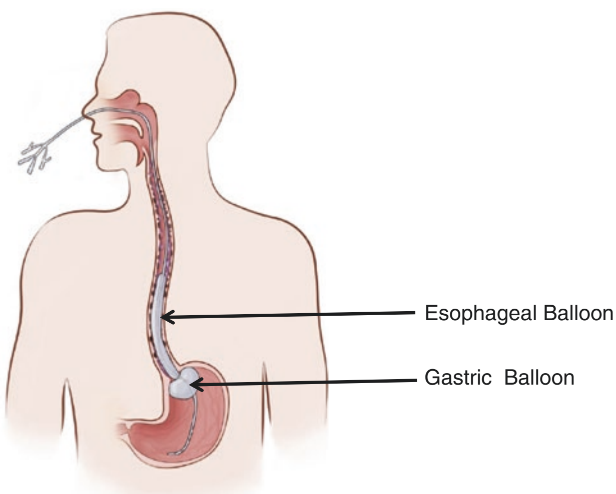


Fig. 32.3 Sengstaken-Blakemore tube with both balloons inflated. Esophageal balloon should only be inflated if bleeding persists significantly after several hours of gastric balloon tamponade

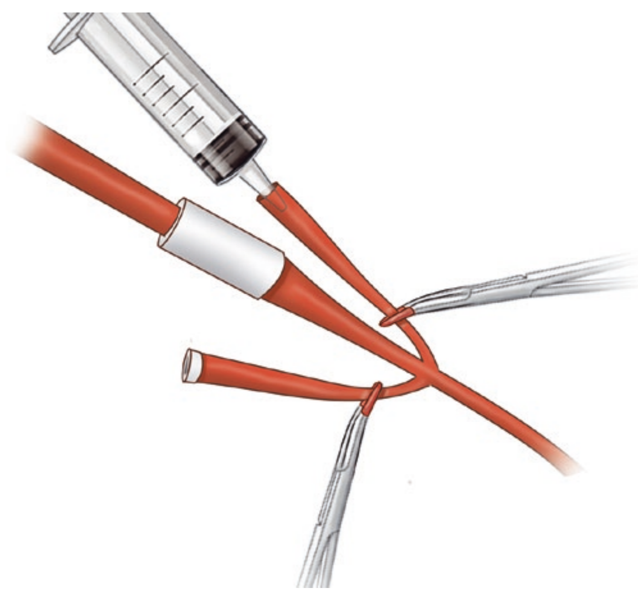


Fig. 32.4 The balloon ports are crucial to clamp after each inflation attempt to ensure volume accuracy

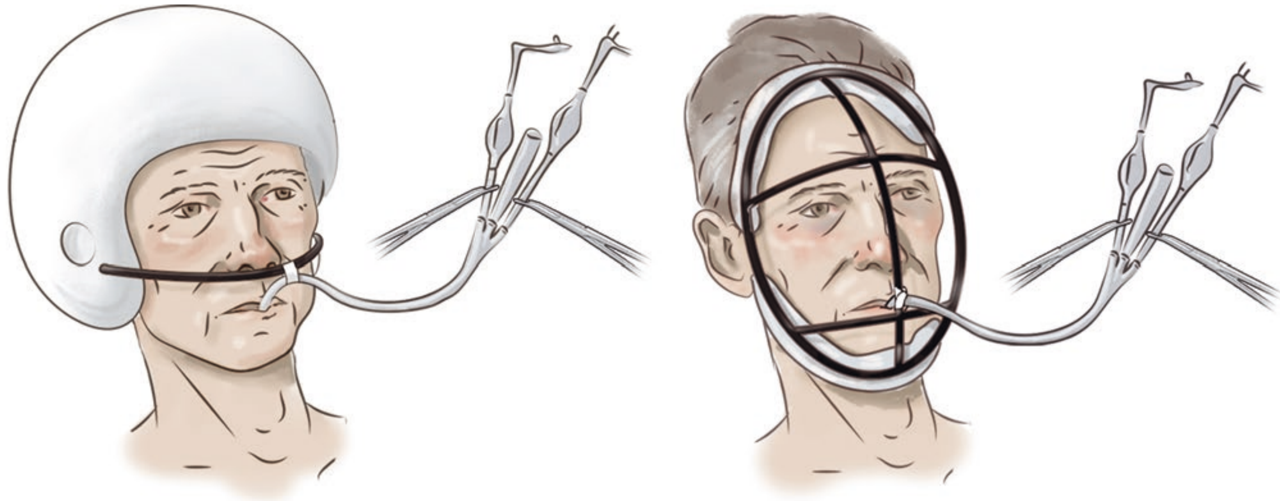


Fig. 32.5 Historically known as the Preston helmet, this allows for traction of the tube to create tamponade

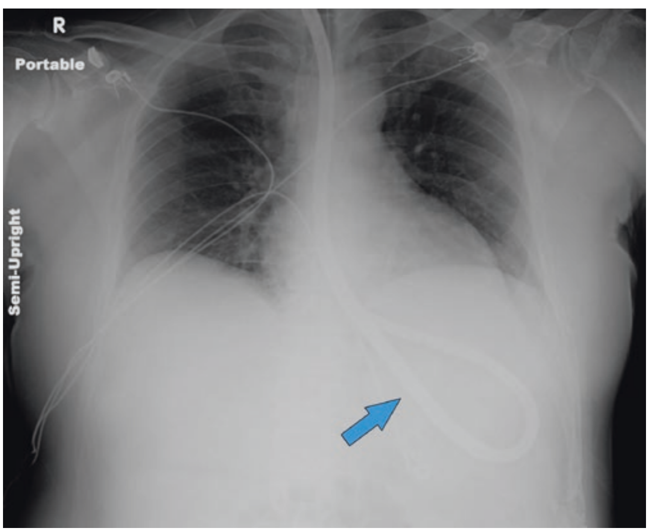


Fig. 32.6 Radiographic confirmation of the tube inside the stomach

32.7 Complications

- Aspiration
- Pressure necrosis
- Esophageal perforation
- Cardiac arrhythmias

32.8 Tips

- Do not forget resuscitative measures including intravenous fluids, blood transfusions, and medications, along with consultations to appropriate services prior to procedure.
- Provide adequate sedation to patients requiring mechanical ventilation along with restraints to prevent pulling of tube.
- When checking the patency of the balloons, consider doing this with the balloon underwater to assess for leaks.
- Never inflate the esophageal balloon before the gastric balloon.
- Esophageal balloon should be deflated 6–12 h prior to deflating gastric balloon.
- Always deflate gastric balloon prior to removal of tube.
- Consider maintaining tube in place after complete deflation in case bleeding recurs and balloon tamponade is again warranted.
- Do not leave tube inflated in place for more than 24–36 h to decrease risk of pressure necrosis.
- Appearance of fresh blood when suctioning the esophageal port can indicate that balloons are not properly inflated or bleeding has recurred.
- Consider taping the ends of the Kelly clamp to decrease damage to the port during clamping.
- If the patient is not to be endotracheally intubated, consider insertion of nasogastric tubes into the mid-esophagus in tubes without esophageal suction ports to decrease risk of aspiration from secretions. Nasogastric tubes can be tied to the tube with sutures to facilitate placement.

Negative Pressure Therapy for Management of the Open Abdomen

33

Erin Palm and Elizabeth R. Benjamin

33.1 Background and Principles

- Indications for the open abdomen include damage-control laparotomy, abdominal compartment syndrome (ACS), severe peritonitis, or need for second-look laparotomy to evaluate potentially compromised bowel (Fig. 33.1). In these situations, temporary abdominal closure (TAC) is performed.
- Contemporary techniques for TAC utilize negative pressure therapy and are designed to prevent evisceration, remove fluid from the abdominal cavity, and preserve abdominal domain.
- There are commercially available NPT devices, such as the ABThera© system, for TAC. Based on institutional availability, an alternative technique, called a Barker vacuum pack, can be constructed from local supplies. These systems have different mechanical properties. The ABThera© system maintains a more consistent negative pressure in the periphery and is more effective in removing peritoneal fluid than the Barker method.
- There is evidence that the ABThera© system is associated with better survival, decreased complications, and shorter time to definitive fascial closure than the improvised Barker vacuum pack.

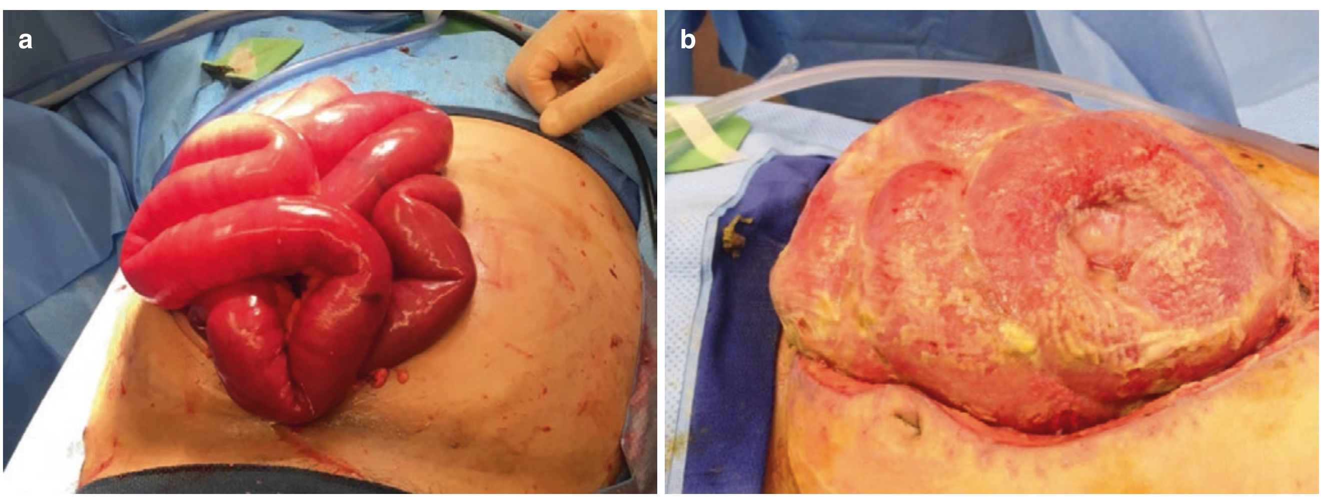


Fig. 33.1 Open abdomen for compartment syndrome (**a**) and severe sepsis (**b**) treated with negative pressure therapy

E. Palm · E. R. Benjamin (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: Elizabeth.benjamin@med.usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_33

33.2 Preparation

- Typically, the first application of temporary abdominal closure is performed in the operating room. However, bedside emergency laparotomy and temporary abdominal closure may be necessary in the ICU in very unstable patients with severe abdominal compartment syndrome. Selected subsequent temporary abdominal closure changes may be done bedside in the ICU, always with strict sterile precautions.
- Prior to application, obtain a commercially available NPT device or the supplies necessary for a Barker vacuum dressing including a sterile plastic sheet (large dialysis bag or X-ray cassette cover), sterile towels or Kerlix rolls, two or more silicone drains, and a transparent adhesive dressing.
- Dressings should be applied using standard sterile technique including full-body drape and personal protective gear.

33.3 Techniques

- There are two commonly used techniques for TAC of the open abdomen:
  - ABThera© NPT system, which includes dressing materials and the portable machine.
  - Barker vacuum pack technique.
- The ABThera© TAC system includes four major component layers.
  - The first layer is the visceral protective layer (VPL). This is a fenestrated nonadherent layer with an embedded foam sponge that is placed directly on the viscera and into the paracolic gutters and pelvis, effectively separating the abdominal contents from the abdominal wall and the remainder of the dressing layers (Fig. 33.2a). The fenestrations allow egress of abdominal fluid, while the nonadherent dressing protects the viscera from direct contact with the foam sponge. Although not necessary, the VPL may be trimmed of excess material prior to placement. If cut, the foam squares should be divided with the residual foam extracted and discarded off the field to ensure that no exposed foam comes in direct contact with the abdominal viscera (Fig. 33.2b, c). The nonadherent layer may be cut to allow placement around ostomies or drains; however care must be taken to avoid exposing the foam inserts with any modifications.
  - The second layer consists of an ovoid foam that may be trimmed to the size of the wound and is placed directly on top of the VPL. This can be placed as a single layer in apposition with the skin edges. Alternatively, an additional layer of foam may be tucked just under the fascial edges on top of the VPL with the second layer of foam placed on top in apposition with the skin edges (Fig. 33.3a–c).
  - The dressing is then covered with an adhesive drape (Fig. 33.4a).
  - A 1-cm-diameter opening is then created in the adhesive drape taking care not to cut into the underlying foam sponge (Fig. 33.4b). The negative pressure tubing and pad are then applied on top of this opening and connected to the negative pressure therapy unit. The negative pressure collapses the foam, applying medial traction to the wound, and removes intra-abdominal fluid that is then collected in the removable canister (Fig. 33.4c).
  - The ABThera© TAC system should be exchanged every 3 days or more frequently in patients with severe peritonitis. When the clinical condition improves, definitive abdominal fascia closure should be done in the operating room as soon as possible.
  - The optimal negative pressure is set at 125 mmHg. However, in the presence of bleeding or concern for

coagulopathy, a lower pressure (25–50 mmHg) should be used due to the increased risk of bleeding associated with negative pressure therapy (Fig. 33.5).

- Barker vacuum pack technique creates a negative pressure system using common materials available in most hospitals (Fig. 33.6).
  - The first layer is also designed as a VPL and is placed over the abdominal contents and into the paracolic gutters and pelvis. This layer can be made from a sterile X-ray cassette cover, dialysis bag, or large 3 L saline bag cut to the appropriate size and manually fenestrated with scissors (Fig. 33.7).
  - The visceral protective layer is then covered with moist towels or gauze (Fig. 33.8).
  - Two large silicone drains are placed over the towels or gauze, and then an additional layer of gauze or towels is applied (Fig. 33.9).
  - A transparent adhesive drape is placed over the wound creating a mesentery at the drain exit sites to maintain a closed seal (Fig. 33.10).
  - The drains are connected to continuous wall suction, manually titrated to produce continuous low suction on the wound.
  - This system, similar to the ABThera© device, should be changed every 3 days or sooner dependent upon the clinical scenario. Definitive abdominal fascia closure should be done as soon as possible, in the operating room.

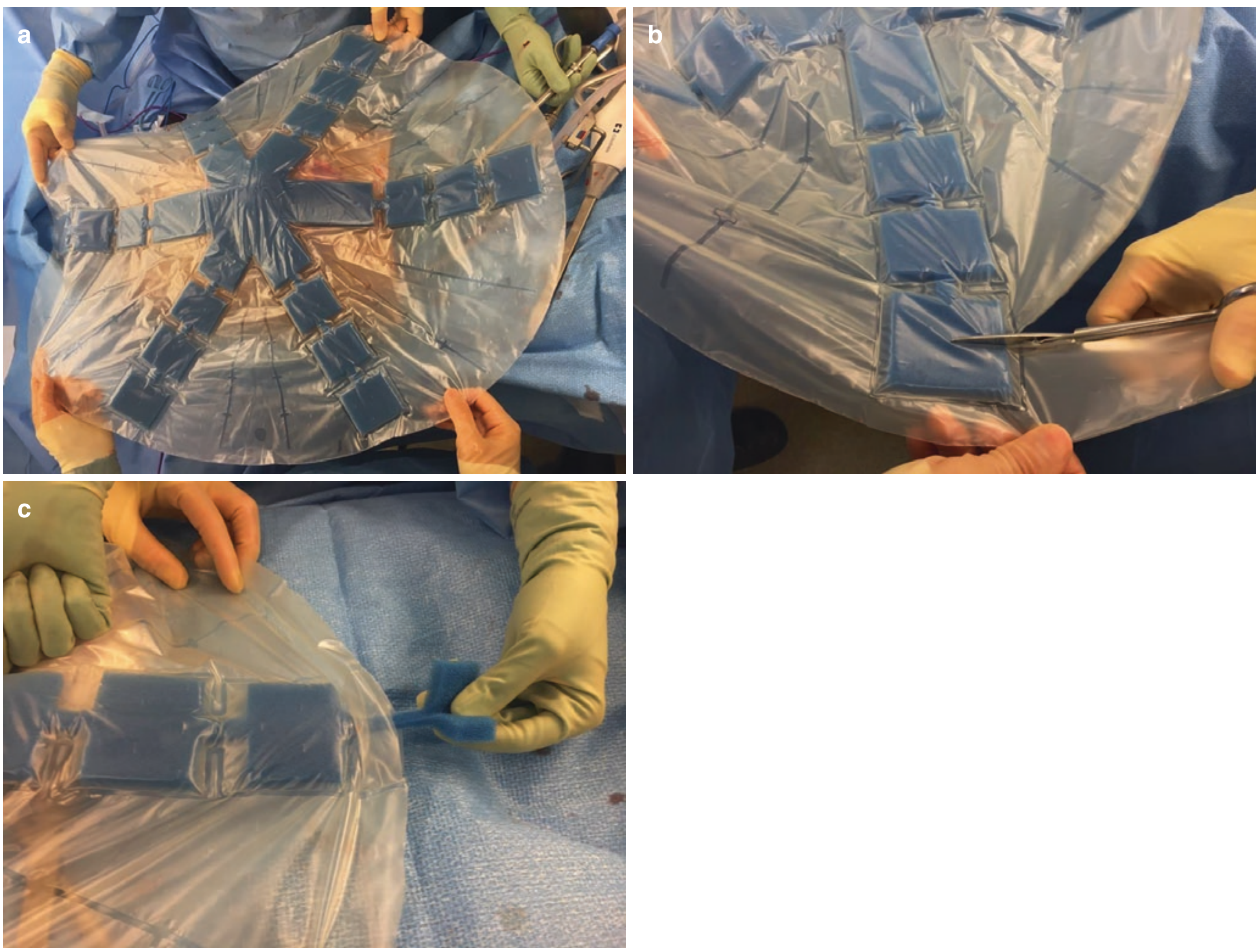


Fig. 33.2 The commercially available AbThera© device has a first layer that is designed as a perforated non adherent layer to cover the abdominal viscera with an embedded foam (**a**). If trimming of the non adherent layer is required, the foam squares should be transected (**b**) and removed (**c**) to avoid direct contact of any foam material with the visceral contents

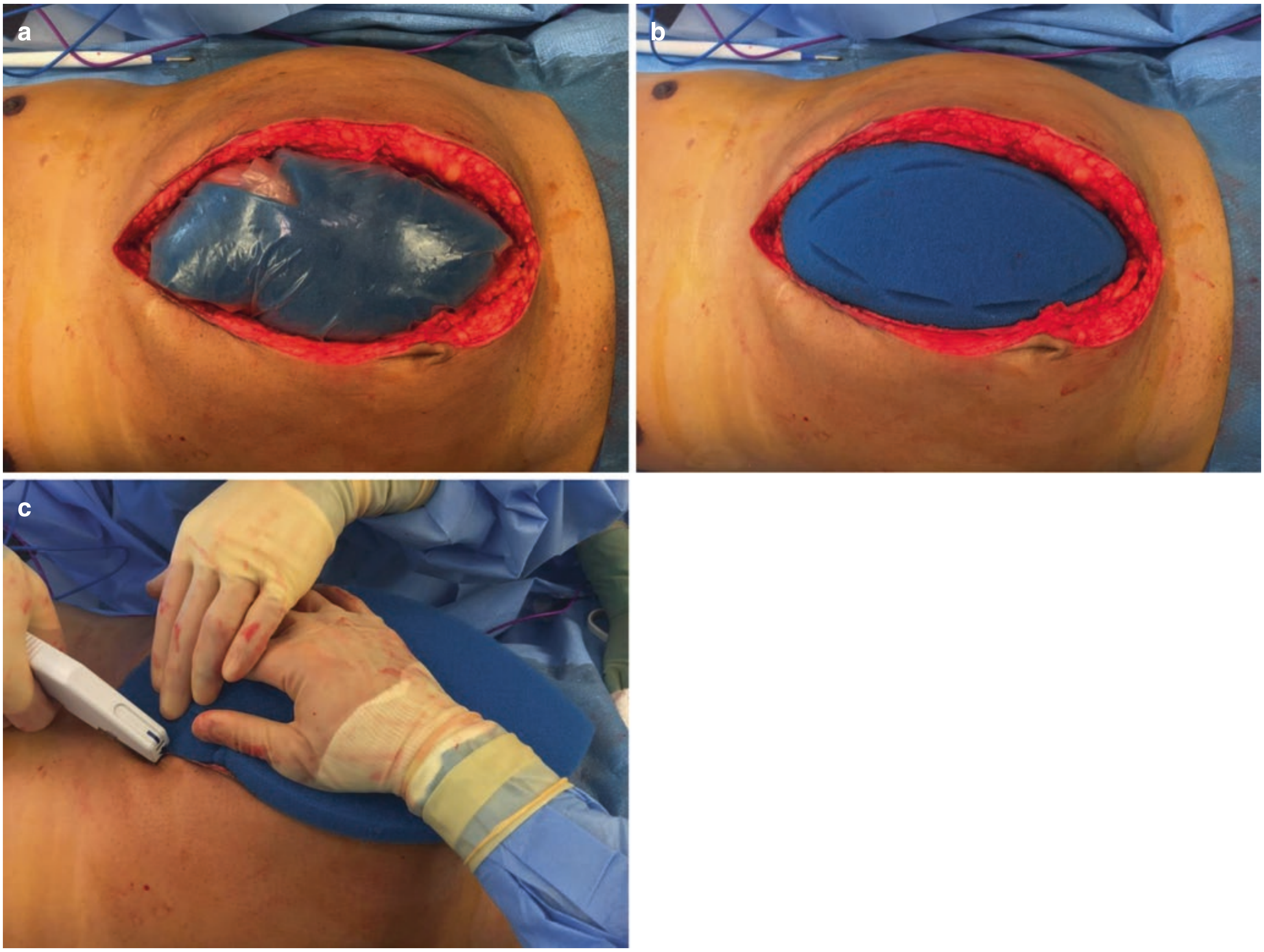


Fig. 33.3 The non adherent layer is placed directly over the abdominal viscera extending to the colic gutters and pelvis taking care to fully cover the abdominal contents (**a**). If desired, an initial layer of foam is placed just under the fascial edges spanning the wound (**b**). This is an optional layer based on the wound characteristics. A sponge is then cut to conform to the the abdominal wound and placed in aposition with the skin (**c**). This may be stapled in place if desired

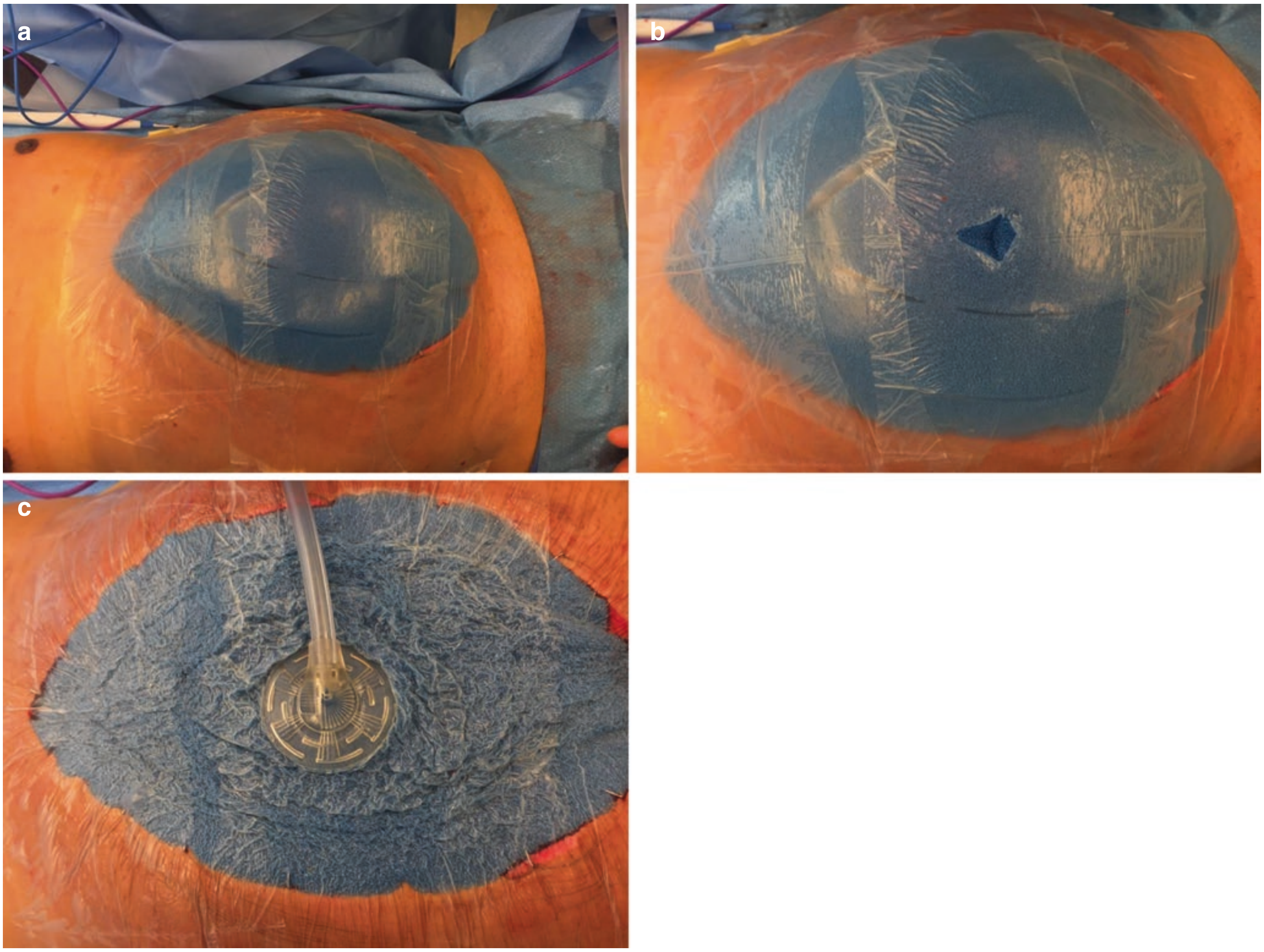


Fig. 33.4 The outer foam is then covered with an occlusive dressing (**a**). A fenestration, approximately 1 cm in diameter is made in the occlusive dressing (**b**) and the suction pad is applied (**c**)

Fig. 33.5 The AbThera© negative pressure pump. The pressure may be set based on the clinical need and the machine will alarm in the event of a leak or loss of suction

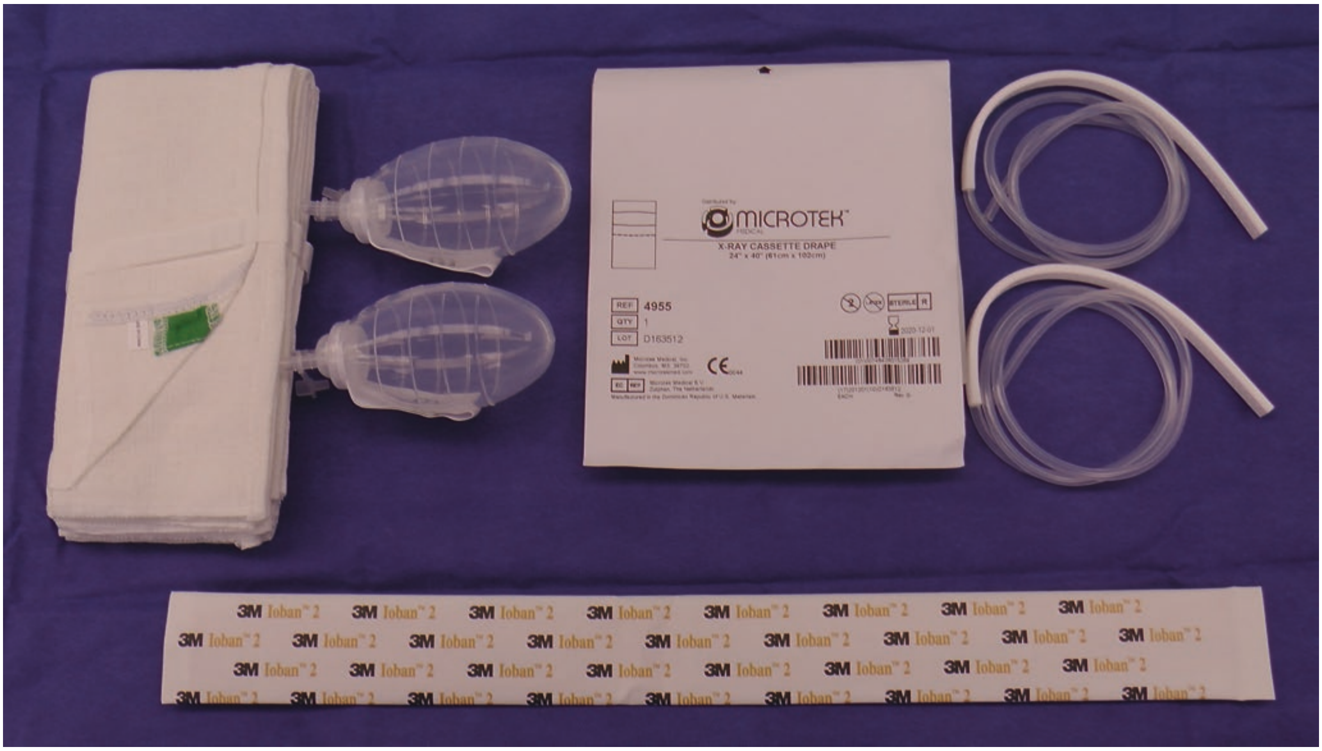


Fig. 33.6 Necessary components for Barker Vac System including a nonadhesive drape, sterile towels with radioopaque markers, suction drains and an adhesive dressing

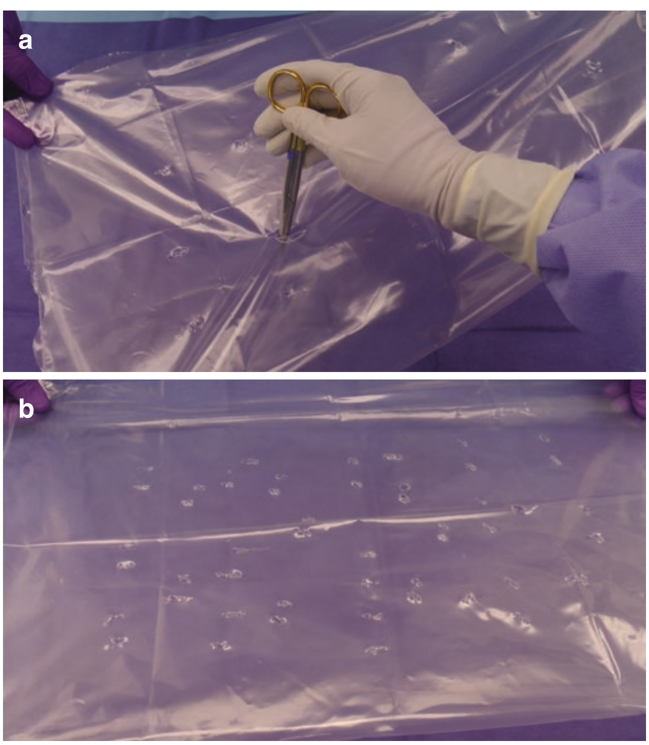


Fig. 33.7 Fenestrations are made in the nonadhesive drape to allow removal of abdominal fluid (**a**). These should be spaced over the area of the drape that will come in contact with the abdominal viscera (**b**)

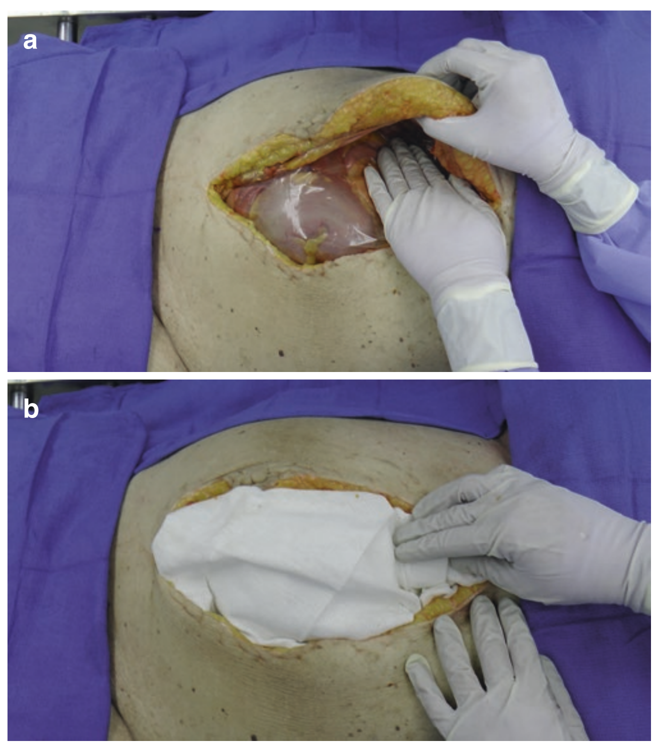


Fig. 33.8 The nonadhesive drape is placed over the abdominal viscera extended deep into the colic gutters (**a**). This is covered with a sterile towel (**b**)

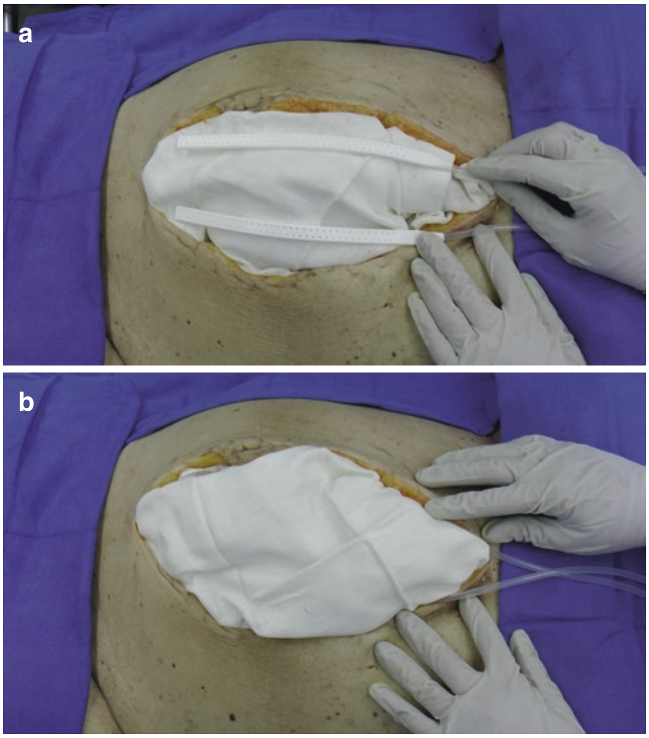


Fig. 33.9 Two closed suction drains are placed on top of the sterile towel (**a**). These are then covered with an additional sterile towel (**b**)

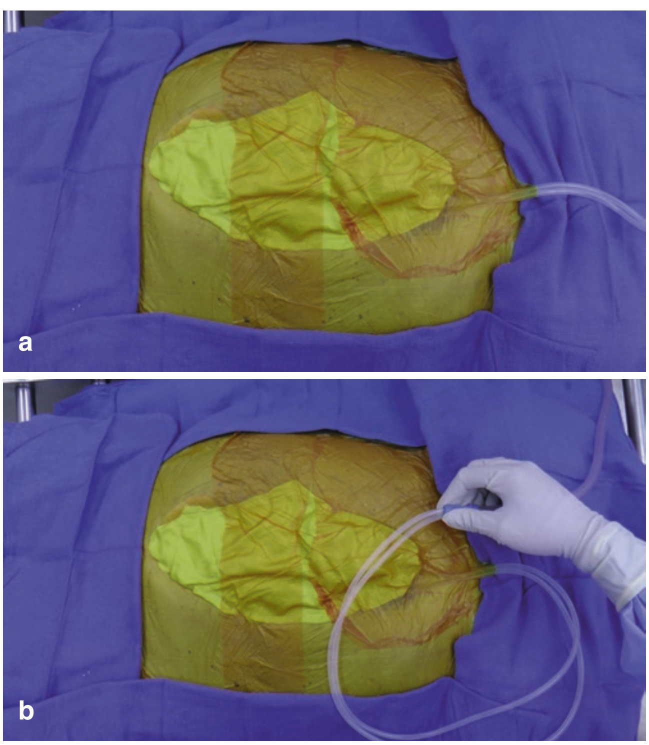


Fig. 33.10 An adhesive drape is placed over the dressing complex leaving a mesentary around the drains to maintain suction (**a**). The drains are then attached to suction to provide negative pressure therapy (**b**)

33.4 Definitive Fascia Closure

- Definitive closure of the abdomen should be achieved as early as possible, ideally with primary closure in less than 5–7 days after the initial laparotomy. Longer delays increase the risk of enteroatmospheric fistulas.
- Judicious, goal-directed fluid resuscitation after damage control helps minimize edema and is associated with improved early closure rates.
- If unable to perform early primary closure, progressive closure with interrupted sutures at the cranial and caudal aspects of the wound on successive operations should be attempted to minimize the fascial defect. Ultimately, a persistent fascial defect may be bridged with biologic mesh to allow for early definitive closure.

33.5 Tips and Pitfalls

- Negative pressure therapy may exacerbate bleeding in the coagulopathic patient. In cases with concern for hemorrhage, low-pressure settings (25–50 mmHg) should be initiated. If ongoing bleeding occurs, the negative pressure therapy should be immediately discontinued and the patient brought back to the operating room for exploration and hemostasis.
- Although the abdomen is open, intra-abdominal hypertension or compartment syndrome may still occur with negative pressure therapy TAC devices. Bladder pressure measurements should be routine in these patients in the early postoperative period.
- Meticulous application of the visceral protective layer is imperative. Direct contact of the foam with the bowel increases the risk of fistula formation.
- When trimming the ABThera© VPL, discarded sponge inserts should be immediately removed from the operative field to avoid inadvertent incorporation into the abdominal dressing. The foam layers of the ABThera© device are not radiopaque.

34 Local Management of Enteroatmospheric Fistulae

Elizabeth R. Benjamin and Demetrios Demetriades

34.1 Background

- Enteroatmospheric (EA) fistula is a dreaded complication of abdominal surgery with varied etiology including anastomotic dehiscence, prolonged open abdomen after damage control surgery, severe abdominal sepsis, decompressive laparotomy for abdominal compartment syndrome, inadvertent serosal injury during adhesiolysis, or incorporation of a bowel loop in an abdominal closure or hernia repair (Fig. 34.1).
- Characterizing the anatomic location and quantifying the daily output of the fistula prior to treatment are imperative. Distal obstruction, residual malignancy, or active inflammatory bowel disease should be ruled out. Associated intra-abdominal infection should be controlled by surgery, percutaneous drainage, or antibiotics, prior to definitive fistula management.
- The guiding principles of EA fistula management include nutritional support, isolation and containment of enteric contents with protection of the surrounding tissue, and delayed definitive surgical treatment.
- Negative pressure therapy combined with fistula isolation devices may be effective at isolating the fistula while preparing the surrounding wound bed for grafting or secondary closure.
- Patients with EA fistulae do not need to be kept NPO unless oral intake significantly affects the quantity of fistula output.

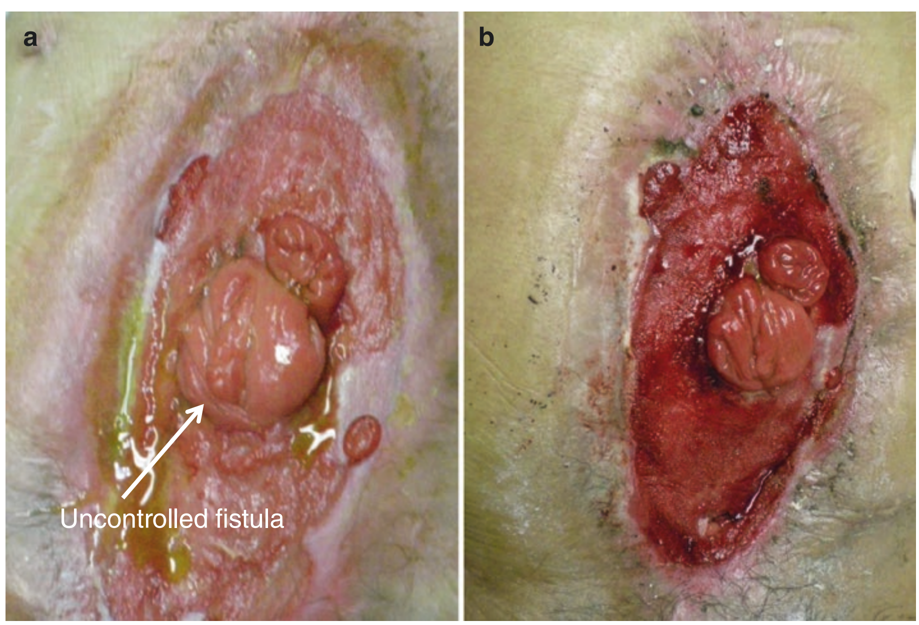


Fig. 34.1 Enteroatmospheric fistulae

E. R. Benjamin · D. Demetriades (✉)
Division of Trauma, Emergency Surgery and Surgical Critical Care, University of Southern California, Los Angeles, CA, USA
e-mail: demetria@usc.edu

D. Demetriades et al. (eds.), *Atlas of Critical Care Procedures*, https://doi.org/10.1007/978-3-319-78367-3_34

34.2 Equipment

- Standard commercially available VAC systems
- Fistula isolation devices
  - Fistula isolation devices are commercially available products, designed to isolate the fistula and apply negative pressure therapy to the surrounding wound bed. They include the fistula funnel, fistula crown, and fistula isolation strip (Fig. 34.2).
  - In some cases custom-made devices can be constructed from inert materials, such as baby bottle nipples.
  - The selection of the fistula isolation device depends on the size, location, and number of EA fistulae.

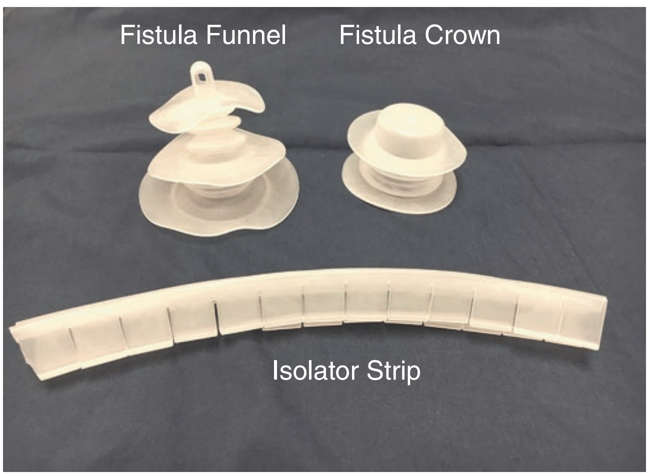


Fig. 34.2 Commercially available fistula isolation devices (Fistula Solution®) including a fistula funnel, crown, and isolator strip designed for fistulae of differing morphology

34.3 Techniques

- Select a fistula isolation device, according to the size, location, and number of EA fistulae. Trim the device as needed (Fig. 34.3).
- Trim the VAC foam to the size and shape of the open abdomen. Mark on the foam the size and site of the EA fistula.
- Create an opening in the foam sponge, approximately the size of the fistula, centered over the fistula opening. Insert the fistula device into the created opening in the foam to allow the base and top flanges to lie on the superior and inferior aspects of the foam sponge (Figs. 34.4 and 34.5).
- The bowel surrounding the EA fistula should be protected with Vaseline gauze or white foam. The black foam should never be placed directly over the exposed viscera.
- Place the entire dressing over the open abdomen with the fistula device exactly over the EA fistula.
- Seal complex with transparent adhesive drape. Cut an opening in the adhesive drape, directly over the fistula device (Figs. 34.6, 34.7, 34.8, 34.9 and 34.10).
  - Cut a 1 cm fenestration over the adhesive drape, away from the fistula device, and apply the suction pad. Connect the suction pad to the VAC pump at a pressure of 50–125 mmHg.
  - Once negative pressure is initiated, inspect the dressing for adequate seal at the base of the fistula funnel. If a leak is noted at the base of the funnel, apply stoma paste to the inner rim of the ring to improve the seal.
  - Apply an ostomy bag to the fistula device to collect effluent.
  - The system should be checked for leaks on a regular basis. If there are no leaks, the VAC dressing may be changed every 3–4 days or as needed.

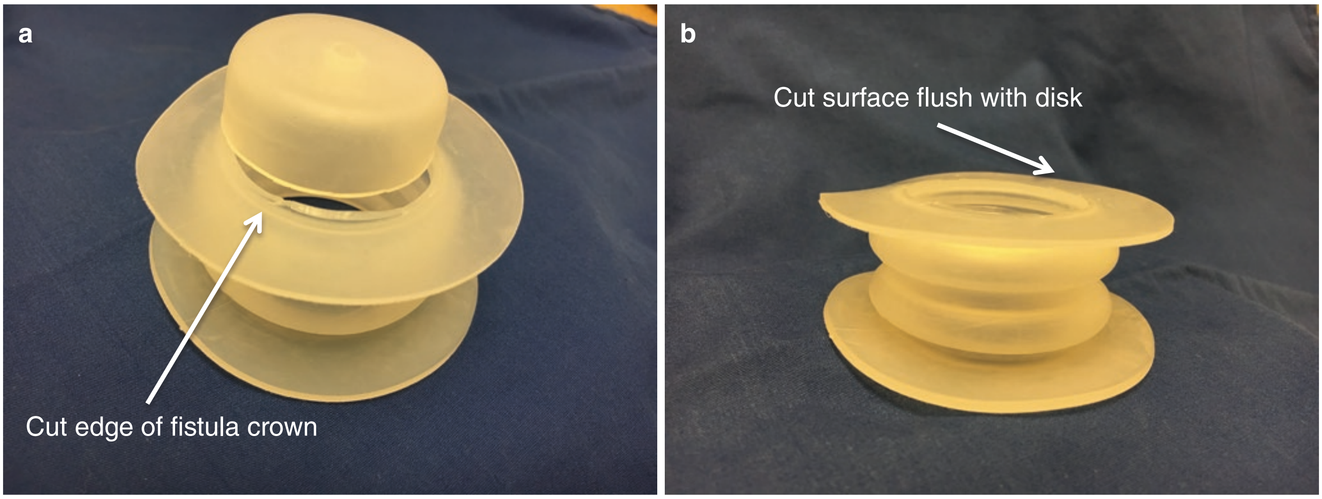


Fig. 34.3 Trim the fistula funnel or crown to the appropriate size and shape (**a**). Make sure that the cut edge is flush with the inferior disk that will be in apposition to the tissue surrounding the fistula (**b**)

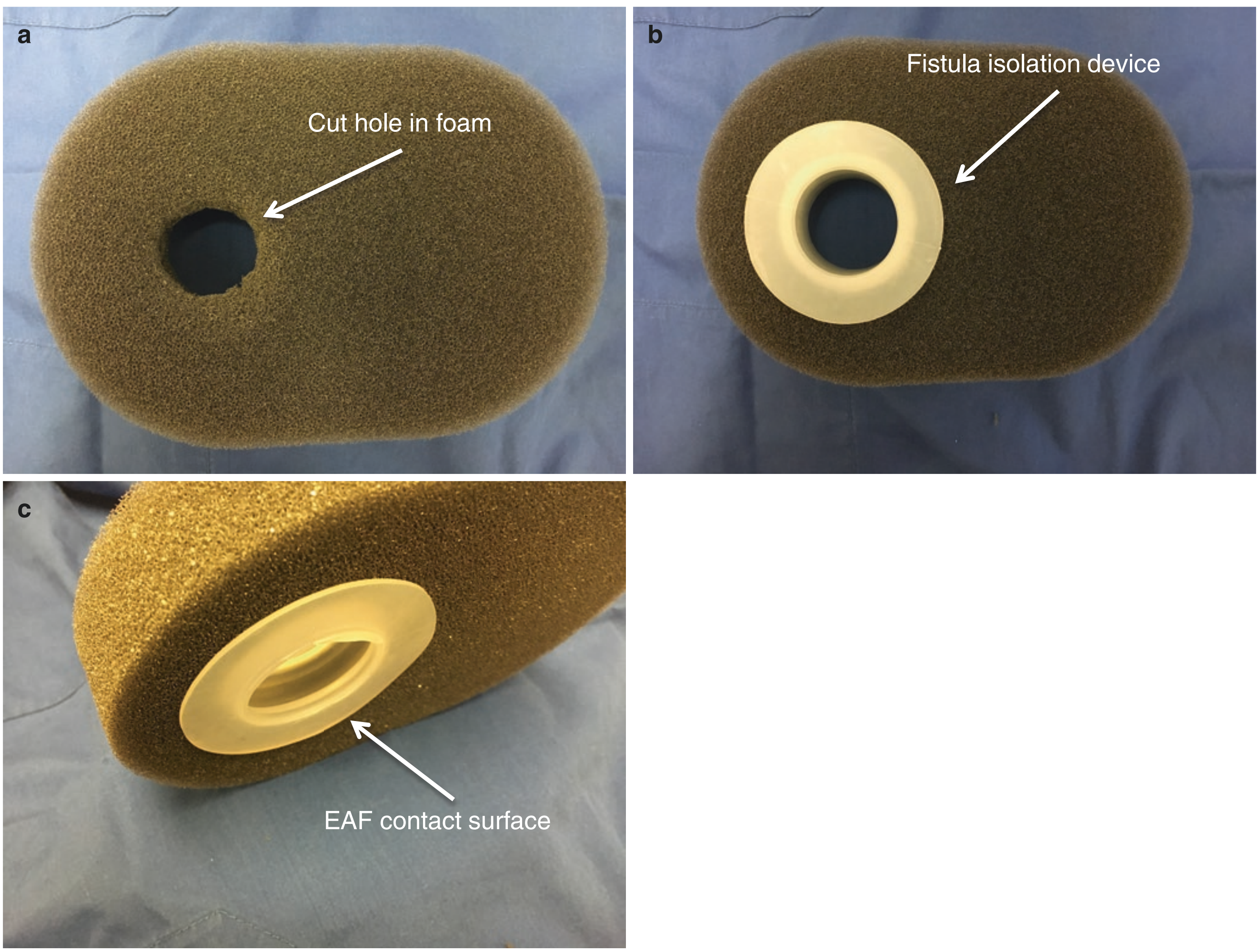


Fig. 34.4 Cut a hole in the foam sponge over the area of the fistula (**a**). Insert the trimmed fistula crown or funnel into the cut area (**b**) allowing the top and bottom disks to span the depth of the foam sponge (**c**)

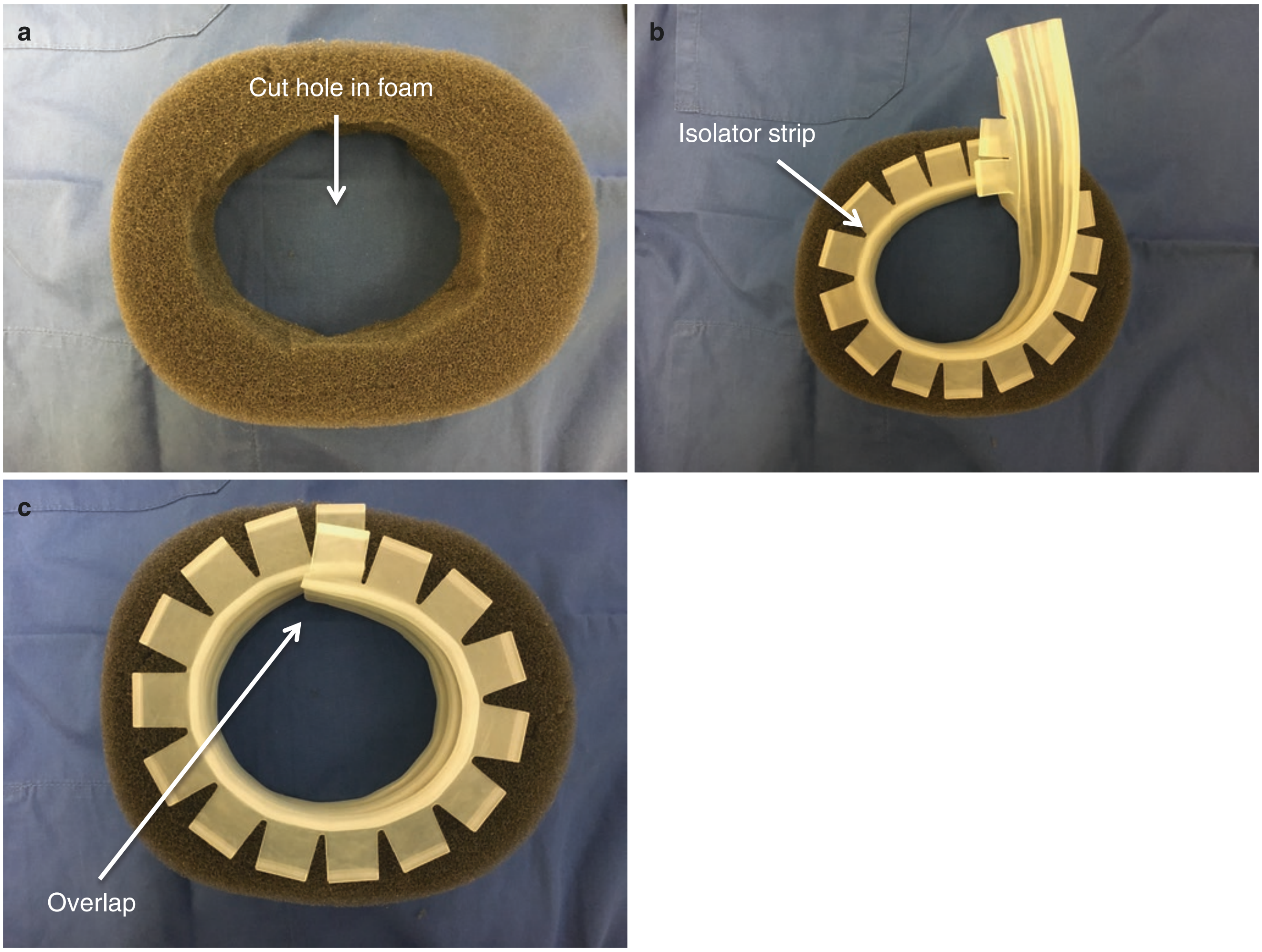
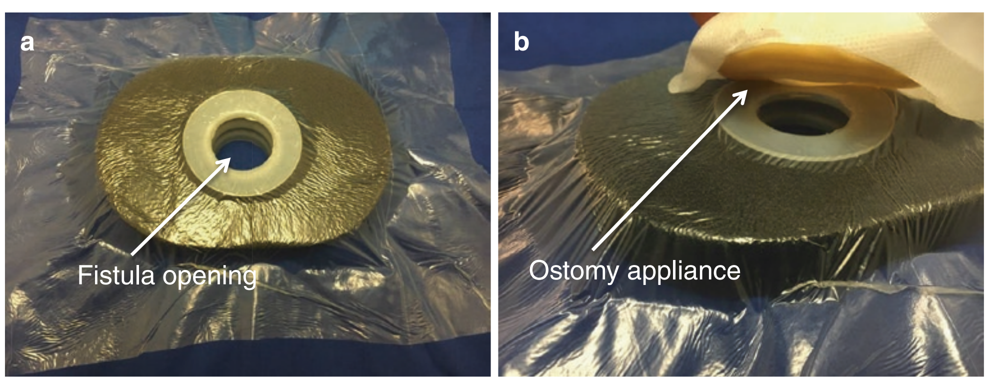


Fig. 34.5 For the isolator strip, cut the sponge aperture to the desired size and shape (**a**) and fit the isolator strip circumferentially around the fistula edges (**b**). Trim the isolator strip to allow a one disk overlap (**c**)

Fig. 34.6 Cover the fistula solution + foam dressing complex with an adhesive drape (**a**), cut the drape over the fistula opening and apply an ostomy appliance (**b**)



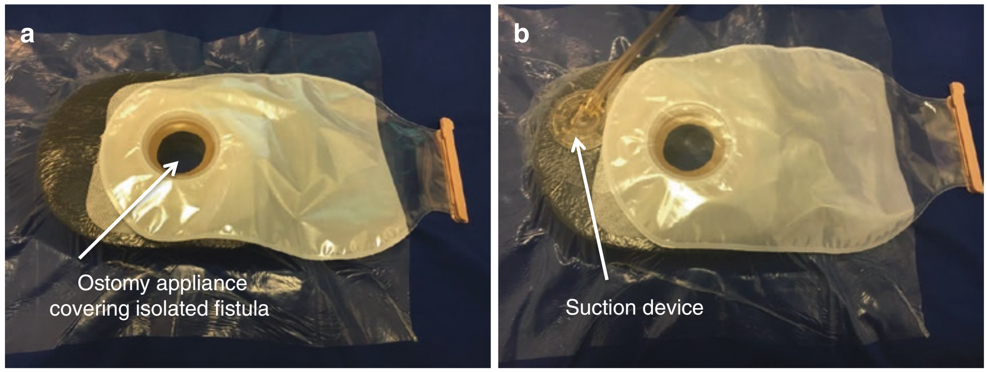


Fig. 34.7 Make sure there is an adequate seal to separate the sponge from the fistula before applying the ostomy bag (**a**). Cut an additional hole in the adhesive drape and connect the suction pad to the surrounding foam sponge (**b**)

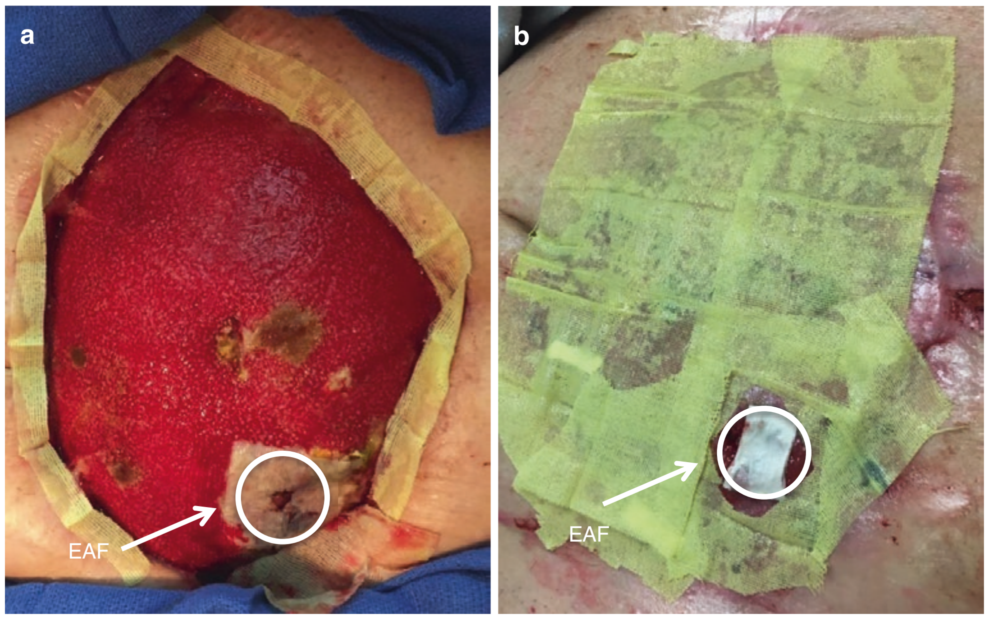


Fig. 34.8 Patient with an enteroatmospheric fistula (**a**). The wound bed is protected with vaseline gauze (**b**). The fistula is isolated using a fistula crown embedded in foam sponge (**c**)

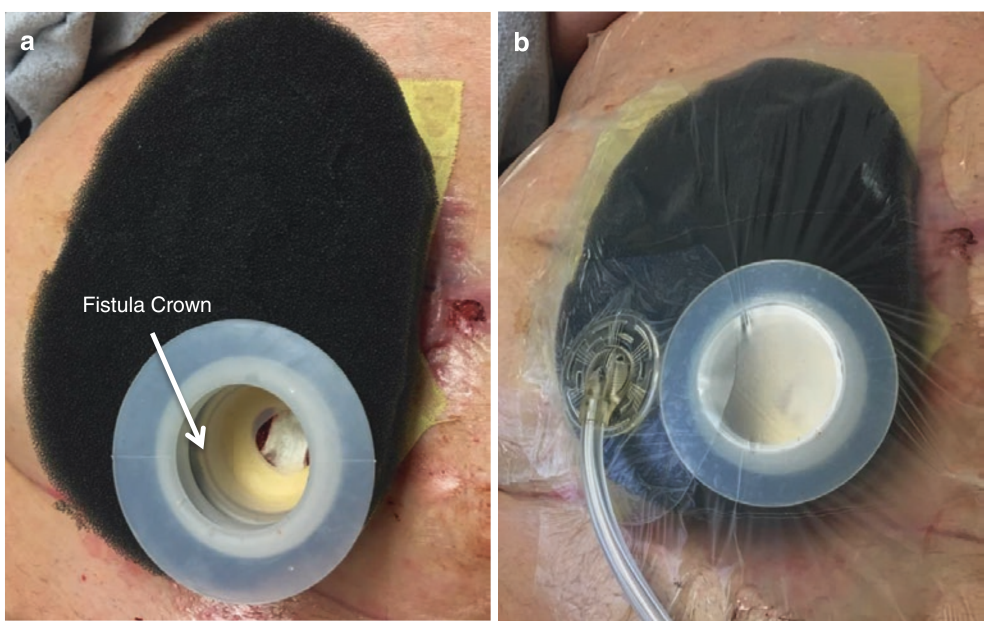


Fig. 34.9 The fistula is isolated using a fistula crown embedded in foam sponge (**a**). The foam sponge and fistula crown are covered with an adhesive drape and an suction pad is applied over a 1 cm fenestration (**b**)

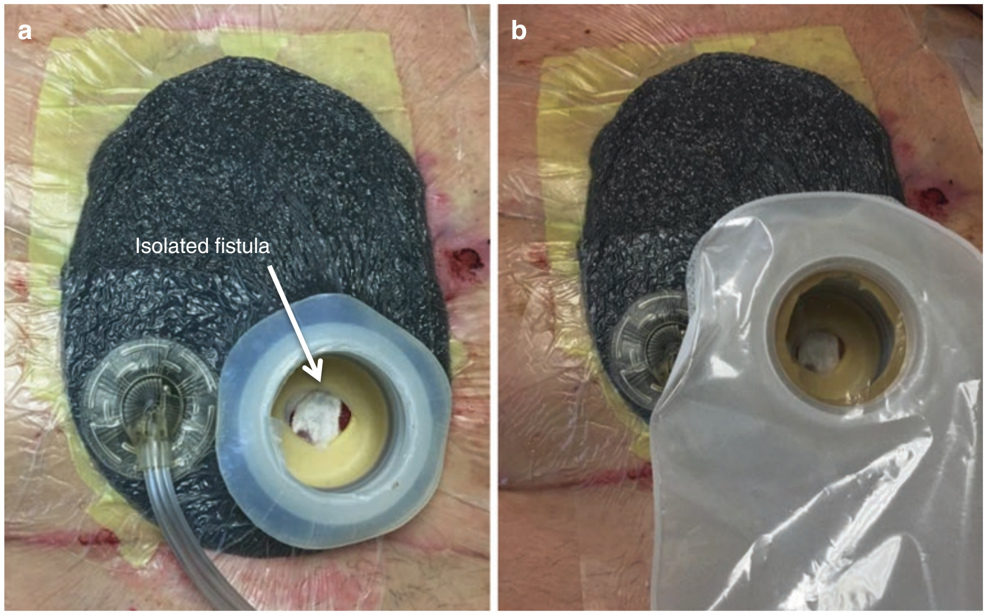


Fig. 34.10 The adhesive is removed from the fistula crown and suction applied to the sponge (**a**). Once the fistula is isolated from the surrounding dressing, an ostomy appliance is placed over the aperture of the fistula crown to collect the fistula effluent (**b**)

34.4 Tips and Pitfalls

- Avoid intubation of the fistula lumen with a Foley or other catheters. This method is ineffective at sustained fluid containment and often leads to enlargement of the fistula opening (Fig. 34.11).
- When using the fistula devices, be careful to trim cut ends flush with the appropriate disk to avoid pressure ulceration on the wound bed from an uneven device.
- The exposed viscera should always be protected with petroleum gauze (Vaseline gauze) or white foam before applying the black foam.
- As with all negative pressure therapy systems, if bleeding is noted in the suction canister, halt negative pressure therapy immediately, and remove the dressing to evaluate for hemorrhage.

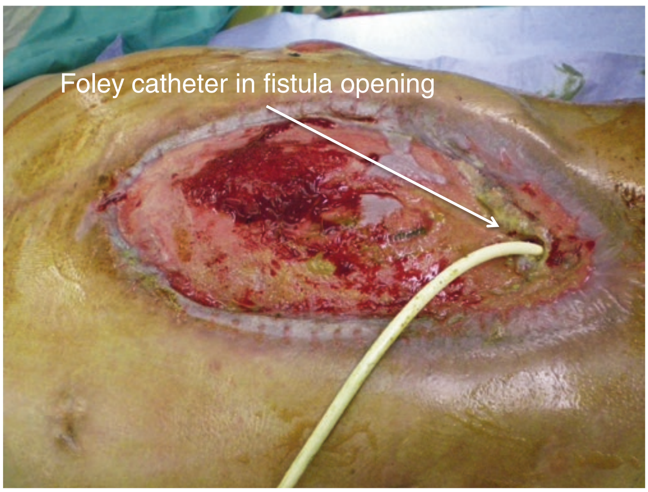


Fig. 34.11 Enteroatmospheric fistula intubated with a foley catheter. This practice is ineffective at fistula isolation and often increases the size of the fistula